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INSTRUCTION MANUAL

MODEL 34A

RESONANT COAXIAL-LINE

34A
b-179

MP MASTER
MA24746

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SECTION I

INTRODUCTION

1.1 PURPOSE

The Boonton Model 34A Resonant Coaxial-Line, when coupled to a Model 102D Signal Generator and a Model 92B RF Millivoltmeter, provides an accurate high frequency system for measuring the effective series resistance (esr), effective capacitance, and Q-factor of both leaded and unleaded capacitors.

1.2 GENERAL THEORY

A resonant, coaxial transmission-line, short-circuited at one end and open-circuited at the other, whose fundamental resonant frequency and Q-factor are known, is perturbed with a test component connected either in series at the short-circuited end of the line, or in shunt at the open-circuited end of the line.

The addition of the component to the line alters the resonant frequency of the system, and the combined Q-factor of the test component and the line is measured using the Δf technique at the newly established resonant frequency. This Q-factor and the parameters of the resonant line, applied in the proper equation, will yield the esr and Q-factor of the test element, as well as the effective capacitance.

1.3 COMPONENT CONNECTION

Unleaded chip capacitors are connected in series with the line between the center conductor and the shorting plunger affixed to a plate at the end of the line. Leaded components may be connected across the open-circuited end of the line between the center conductor and the outer wall using clamping means provided. With this connection, of course, the effect of the resistance and inductance of the leads will be evidenced in the measured parameters.

Special fixtures for radial leaded capacitors and variable piston capacitors are available and are described in Sections IV and V.

NOTE: If the measurement of axial leaded monolithic chip capacitors without the influence of the leads is an important requirement, the Model 34A-01 should be used. This version permits series mode measurements by placing the leads in slots provided in the connecting plunger and center conductor of the line. Swallowing the leads in this manner allows measurements to be made directly at the body terminals of the component without altering the leads. Maximum lead length that the Model 34A-01 can accommodate is 1 inch (2.54 cm).

1.4 OTHER MEASURING METHODS

Attempts at measuring high Q-factors of capacitors at high frequencies with admittance or impedance bridge techniques have been generally unsuccessful, principally because of imperfect bridge components and the extreme resolution needed to separate the loss from the major parameter when the Q-factor is several hundred, or more.

Q-meters have been used with some success to measure the loss of capacitors having modest Q-factors. For high Q-factors, the uncertainty of the indirect measurement is sufficiently great to make the effort questionable. In some instances the measured Q-factor may even be negative.

It has been suggested that S-parameters be used to determine the loss of capacitors at high frequencies. Unfortunately, the resolving power and accuracy of present state network analyzers are inadequate for this purpose, and calculations based upon swept measurements of S_{11} and S_{21} produce random positive and negative numbers which bear no relationship to the actual loss of the test capacitor.

1.5 ADVANTAGES OF THE MODEL 34A

The Model 34A Resonant Coaxial-Line offers advantages for the measurement of Q-factors of capacitors at high frequencies: there are no adjustable elements to alter circuit conditions in an unprescribed manner; the only variable is frequency which can be measured with an accuracy of 1 ppm, or better; the loss of the line, as a function of frequency, is predictable; the Q-factor of the line is sufficiently high to support accurate measurements of low-loss capacitors; and, the facility with which the slotted center conductor can be parted permits insertion of unleaded components with little degradation of initial conditions.

The success of the measurement system is the result of having:

a. A stable signal source of low distortion, high output level, and digitally displayed output frequency with 100 Hz resolution.

b. A sensitive rf millivoltmeter with a low capacitance, low conductance, probe.

c. A resonant coaxial-line having definable losses and suitable fixturing to accept both unleaded and leaded components, as well as other configured components.

d. A programmable calculator for the computation of esr, capacitance, Q-factor, and other parameters.

e. A proper analysis of the system and the attendant equations which yield the desired parameters of the test specimen.

1.6 MEASUREMENT FREQUENCIES

The frequencies at which a capacitor can be measured are a function of the length of the coaxial line and the capacitance of the test specimen. The line length for the Model 34A was selected to allow capacitors to be measured in frequency bands for which there is general demand.

The following table shows ranges of frequency and related capacitance for measurements in both the shunt and series mode.

TABLE 1-1

CAPACITANCE RANGE Shunt Mode (pF)	FREQUENCY RANGE (MHz)		CAPACITANCE RANGE Series Mode (pF)	
425 to 0	20 to 130	130 to 250	1000 to 1.0	(1/4)λ
60 to 0	270 to 390	390 to 500	1000 to 1.0	(3/4)λ
30 to 0	530 to 650	650 to 750	1000 to 1.0	(5/4)λ
18 to 0	790 to 910	910 to 1000	1000 to 1.0	(7/4)λ
13 to 0	1050 to 1170	1170 to 1250	1000 to 1.0	(9/4)λ

For frequencies above 520 MHz, the Model 102-1A Frequency Doubler must be used at the output port of the Model 102D Signal Generator. If the full range of the Model 34A is to be used on a regular basis, a dual coaxial switch may be arranged to switch the doubler in and out of the system.

Above approximately 600 MHz, accurate measurements require the use of the Model 34-1A High Impedance RF Probe and the Model 34-2A Cut-Off Attenuator, and for specimens with high Q-factors, we recommend the use of the attenuator at all frequencies.

1.7 MEASURED PARAMETERS

The evaluation of each component requires the measurement of only two frequencies, one on each side of the resonant response at a predetermined ratio of resonant to off-resonant voltage. When these two frequencies are entered in a programmed calculator, in which the coaxial-line parameters have been stored, the values of C, Q, and esr, and the measurement frequency, f_1, are obtained.

SECTION II

SPECIFICATIONS

2.1 ELECTRICAL SPECIFICATIONS

CAPACITANCE RANGE[1]	0 to > 100 pF
Series mode:	< 1.0 to > 1000 pF in five frequency bands from 130 to 1250 MHz. Refer to Par. 1.6 and Section III.
Shunt mode:	0 to 425 pF from 20 to 130 MHz 0 to 60 pF from 270 to 390 MHz 0 to 30 pF from 530 to 650 MHz 0 to 18 pF from 790 to 910 MHz 0 to 13 pF from 1050 to 1170 MHz Maximum values of capacitance shown are not absolute limits, but the influence of lead resistance and inductance becomes immoderate as both capacitance and frequency increase.
FREQUENCY RANGE[1]	
Series mode:	130 - 250 MHz, 390 - 500 MHz, 650 - 750 MHz[2], 910 - 1000 MHz[2], 1170 - 1250 MHz[2]
Shunt mode:	20 - 130 MHz, 270 - 390 MHz, 530 - 650 MHz[2]
TEST LEVEL	
Series mode:	Approximately 3 mA, or less
Shunt mode:	Approximately 0.2 volt, or less
ACCURACY	Certification for Q-factors of capacitors at high frequencies is not presently available from the National Bureau of Standards. A conservative analysis of the sources of error for the 34A measurement system indicates an uncertainty of measurement for Q-factors that is generally within $\pm(5 + Q^{0.35})\%$.

[1]Capacitance and frequency are interdependent. See Section III.

[2]Use Boonton Model 102-1A Frequency Doubler above 520 MHz, and Model 34-1A RF Probe and Model 34-2A Cut-Off Attenuator above 600 MHz.

ACCURACY (continued):

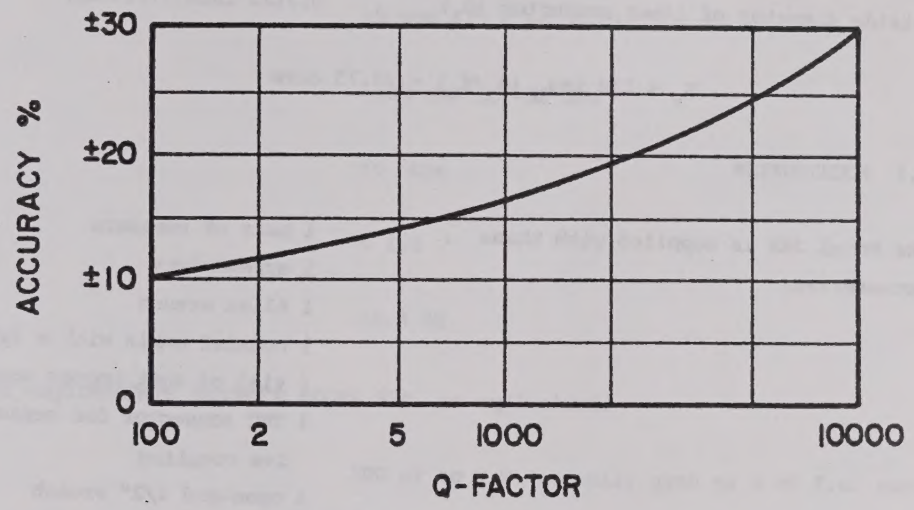

Figure 2-1.

2.2 MECHANICAL SPECIFICATIONS

Overall length	24.2 inches (61.5 cm)
Width	2 inches (5.1 cm)
Height	2 inches (5.1 cm)
Maximum component body length for series measurement	0.3 inch (7.6 mm)
Maximum component lead length that can be swallowed for a series measurement (Model 34A-01, only).	1 inch (2.54 cm) each lead
Spacing of contacting clamps for shunt measurement	0.6 inch (15.2 mm)
Minimum component lead length for shunt measurement	Approximately 0.7 inch (17.8 mm)

Inside diameter of outer conductor (d_1)	1.106 inches (2.81 cm)
Outside diameter of inner conductor (d_2)	0.3125 inch (7.94 mm)

$$Z_0 = 138 \log_{10} (d_1/d_2) = 75.75 \text{ ohms}$$

2.3 ACCESSORIES

The Model 34A is supplied with these accessories:	1 pair of tweezers 1 screwdriver 1 Allen wrench 1 coaxial cable with a type N and TNC connector 1 vial of soft copper squares 1 TNC connector for capacitive or modified inductive coupling 1 open-end 1/2" wrench 1 walnut storage case 1 Model 34-2A Cut-Off Attenuator
Optional Accessories Available:	34-1A High Z RF Probe 34-3A Radial Lead Swallowers (shunt measurement only) 34-3B Radial Lead Swallowers with built-in series capacitor (shunt measurement only) 34-4A Piston Capacitor Adapter, 15/64 inch × 64 threads/inch 34-4B Piston Capacitor Adapter, 0.120 inch × 80 threads/inch 102-1A Frequency Doubler

2.4 SIGNAL GENERATOR REQUIREMENTS (BOONTON MODEL 102D, or equivalent)

Frequency Range	40 to 1250 MHz (with frequency doubler)
Frequency Display	Six or seven significant digits with 100 Hz resolution. Display *must* show changes of vernier frequency control in phase locked mode.
Frequency Stability	< 0.2 ppm/hr. after 1 hour warmup

Spurious Output	> 30 dB below carrier level
Frequency Accuracy	±2 ppm (15 C to 35 C)
RF Power Output	-130 dBm to +13 dBm
Output Impedance	50 ohms
Source VSWR	< 1.5
Leveling	±0.5 dB

2.5 RF MILLIVOLTMETER REQUIREMENTS (BOONTON MODEL 92B, or equivalent)

Voltage Range	200 µV to 3 V (normally used on 3 mV f.s. range)
Input Capacitance	Approximately 2 pF without probe tip at an input level of 3 mV
Input Conductance	< 200 µS at 100 MHz and an input level of 3 mV
Accuracy	
(absolute)	±(1% f.s. + 3% rdg) to 700 MHz
(relative)	Half-scale voltage is within ±1% of correct value, relative to full-scale reading on 3 mV f.s. range for a minimum period of 6 months following calibration.
Voltage Display	Linear analog, taut-band meter with mirror-backed scale and knife edge pointer. Voltage scales: 0 to 3 (0.05/div.) and 0 to 10 (0.1/div.). The Boonton Model 92BD Digital RF Millivoltmeter is *not* recommended for this application.

2.6 HIGH IMPEDANCE RF PROBE (BOONTON MODEL 34-1A)

Voltage Range	200 µV to 3 V
Input Capacitance	Approximately 1.2 pF without probe tip at an input level of 3 mV
Input Conductance	Approximately 10 µS at 100 MHz and a level of 3 mV Approximately 50 µS at 1 GHz and a level of 3 mV
Accuracy (relative)	Same as 91-12F RF Probe supplied with Model 92B RF Millivoltmeter, on 1, 3, 10, and 30 mV ranges

WARNING: *This high impedance, Model 34-1A, probe may be damaged if a static charge is directed to the center pin of the probe, or to the two pins in the connector. The probe has been protected during shipment with a conductive bag. Discharge body static before handling the probe. The probe will be safe from this type of damage when it is installed in the 34A and the system is grounded through the generator and the RF millivoltmeter.*

SECTION III

OPERATION

3.1 SYSTEM CONNECTIONS

The Model 34A Resonant Coaxial-Line is shipped with a TNC connector installed at the closed end of the line. Excitation is supplied from the generator through this connector and the inductive coupling loop, which consists of a 50 ohm resistor attached to the connector.

The 12-inch length of coaxial cable, which is supplied with the Model 34A, is equipped with an N and TNC connector, and is used to connect the generator to the resonant coaxial-line, as shown in Figure 3-1.

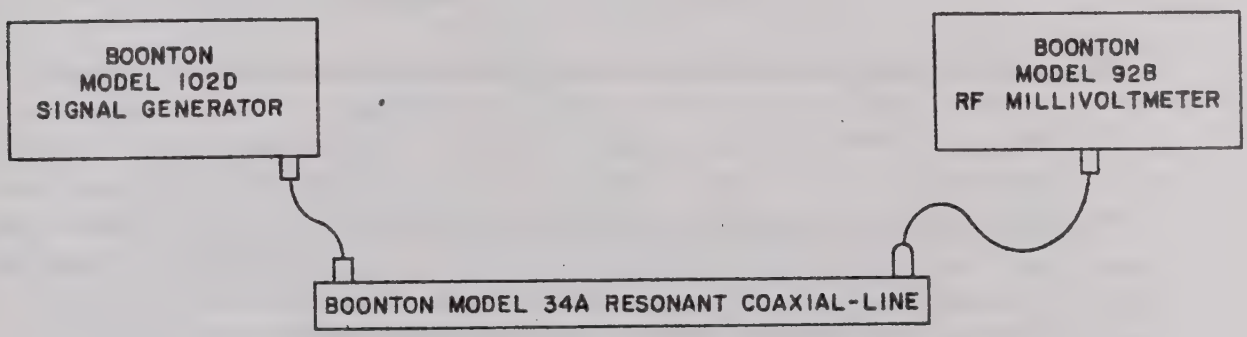

Figure 3-1.

The probe for the Model 92B RF Millivoltmeter should be threaded into the 1/2-20 bushing at the open end of the line. When tightened to the stop, the probe is in position and capacitively coupled to the center conductor of the line. The probe will, therefore, detect the resonant voltage response when the generator is tuned through resonance. The connector at the end of the probe cable must be connected to the input receptacle on the front panel of the Model 92B RF Millivoltmeter, and the ferrule nut should be secured.

3.2 MEASUREMENT FREQUENCIES

The frequency of measurement is a function of the capacitance being tested. The approximate curves of Figures 4-1 through 4-5, and 5-3 through 5-7 relate test capacitance vs. measurement frequency for odd quarter-wavelength modes of operation, from one-quarter through nine-quarters. It is evident from examining the curves that the higher frequency bands are narrower for a given spread of capacitance than for the fundamental mode of $\lambda/4$. For example, the normal range of capacitance for the $(3/4)\lambda$ series mode can be measured at 430 MHz, ±40 MHz, or a total bandwidth of 80 MHz. At the fundamental mode a bandwidth of 110 MHz is needed for the same range of capacitance, i.e., 185 MHz, ±55 MHz.

In the shunt mode, resonance occurs when the effective reactance of the test capacitor equals the inductive reactance of the line. This relationship can be rearranged to show,

$$C = 1/\omega_1 Z_0 \tan\beta_1 \ell \qquad \text{(shunt mode)} \qquad (3\text{-}1)$$

where the electrical length of the line is $\beta_1 \ell$ at the measurement frequency f_1, and,

$$\beta_1 \ell = (f_1/f_0)90^\circ \qquad (3\text{-}2)$$

Resonance occurs in the series mode when the effective reactance is equal to that of the coaxial line, but in this case resonance is always above an odd quarter-wavelength frequency and the line reactance is related to a cotangent function whose negative sign in the second and fourth quadrants must be changed in order to derive a positive value of capacitance.

$$C = -1/\omega_1 Z_0 \cot\beta_1 \ell \qquad \text{(series mode)} \qquad (3\text{-}3)$$

where $\beta_1 \ell$ is the electrical length of the line at f_1, and is given by:

$$\beta_1 \ell = (f_1/f_0')90^\circ \qquad (3\text{-}4)$$

3.3 SERIES AND SHUNT MEASUREMENTS

The Model 34A will accommodate components for both series and shunt connected measurements. The user, however, does not always have a choice. Capacitors without leads, for example, must be measured in the series mode, while shunt measurements can be made only with leaded capacitors.

When measurements must be made on axial-leaded components without the influence of the leads, the Model 34A-01 should be used. This version provides slots in the series fixture which swallow the leads and the fixture makes contact directly at the body of the capacitor. This feature has been eliminated from the Model 34A owing to the inconvenience of the slots when fixturing unleaded chip capacitors.

Parameters measured in the shunt mode include the effects of the lead resistance and inductance. These effects are more pronounced at higher frequencies and for larger values of capacitance. We suggest, therefore, restricting the maximum capacitance for shunt measurements to about 400 pF in the lowest frequency band, and to 15 pF, or less, in the highest band. Larger values can, of course, be measured, but the rise in apparent capacitance and effective series resistance, and the inordinate drop in the effective Q-factor make the significance of such measurements questionable, unless the measurement condition duplicates or approaches that of the actual circuit.

No limit of capacitance exists for a series measurement. If, however, the measurement frequency exceeds the self-resonant frequency of the capacitor and it appears inductive, the calculator program will recognize this and display a negative value for the effective capacitance followed by the equivalent inductance of the component at that frequency.

3.4 SPECIAL FIXTURING

Occasionally, capacitors to be measured will have physical configurations unsuitable for direct series connection in the Model 34A, but without the necessary lead length for a shunt connection. In many cases it should be possible to provide means to connect such capacitors, but it could entail mechanical modifications to the plunger, center conductor, or end clamp. Such modifications must be left, in most instances, to the user who is most familiar with the product to be tested.

When necessary, Boonton Electronics can supply additional parts for the Model 34A, such as plungers and clamps, and center conductors.

The center conductor of the Model 34A can be removed from the housing by removing three binder-head screws from the body of the line, located about 1.8 inches from the closed end of the line. Access to the heads of these screws is facilitated by removing the outer tube and clamps from the base plate. by removing four 10-32 screws in the bottom of the base plate.

Inquiries are invited concerning modifications for special components. A sample of the special component will generally aid us and expedite our comments.

3.5 INPUT COUPLING

When the Model 34A Resonant Coaxial-Line is received, a TNC connector with an inductive coupling loop consisting of a 50 ohm metal film resistor is installed at the closed end of the

line. The angular position of the loop, hence the degree of coupling, will have been adjusted so that when fed from a 50 ohm output port of a signal generator, such as the Boonton Model 102D, at a level of 0 dBm, the Model 92B RF Millivoltmeter, properly installed, will read approximately 3 mV at the quarter-wavelength resonant frequency, approximately 130 MHz.

If this coupling connector is readjusted, or removed to replace it with the connector that capacitively couples energy to the line, upon reinstallation it should be adjusted and locked in position for the conditions described above.

SECTION IV

SERIES MODE MEASUREMENTS OF CAPACITORS

4.1 GENERAL

When the Model 34A series-mode fixture is opened to permit the insertion of a test capacitor for measurement at the short-circuited end of the line, a portion of the center conductor is replaced by the capacitor. Because the effective diameter of the capacitor is usually smaller than the diameter of the center conductor, a discontinuity appears at both points of connection. This has the effect of adding inductance to the line at the points of the discontinuities. It is improper to charge this added inductance to the capacitor, for if the test capacitor had the same effective diameter as the center conductor, this condition would not exist.

Using f_o, the basic resonant frequency of the short-circuited line, in the series mode equations will incorrectly attribute both the discontinuity inductance and the self inductance of the device to the test capacitor.

The discontinuity inductance can be negated by using a frequency for f_o' that is slightly lower than f_o. Although the calculated value of effective series resistance (esr) is sensibly constant (within a few percent) for various values of f_o' in the neighborhood of the correct value, only the use of the proper value of f_o' will yield the correct effective capacitance, hence the proper Q-factor.

Arranging the principal expression for loss in terms of the esr, rather than the Q-factor, greatly reduces its dependence upon f_o'. Furthermore, esr is considered by many manufacturers and users of capacitors to be the more useful parameter for labeling capacitor loss. It is especially significant as self resonance is approached and the total reactance, hence the Q-factor, approaches zero. On the other hand, valid results for esr obtain at frequencies below, near, and above self resonance. There is also the benefit of knowing the i^2r loss when the circuit current is known.

4.2 SERIES MODE MEASUREMENTS OF CAPACITORS

Monolithic chip capacitors are well suited for series mode measurements with the Model 34A Resonant Coaxial-Line. Other capacitors that are physically small enough to fit into the line can also be measured, using special techniques which are described later. Two adapters, Models 34-4A and 34-4B, are available for the convenient fixturing of variable piston capacitors. These adapters also permit the adjustment of capacitance when the capacitors are connected for measurement. Other components, such as small resistors and inductors, can be measured.

The insertion of unleaded capacitors between the contact discs of the center conductor and the movable plunger is generally accomplished with the aid of tweezers provided for this purpose. The plunger should be moved inward to engage and hold the capacitor while the ferrule clamp is tightened to provide a pressure contact. If possible, avoid rotating the plunger after it is engaged to prevent scoring the surfaces of the contact discs.

The integrity of series connections depend on how well the terminal pads of the capacitor mate with the discs. The most repeatable measurements, and those yielding slightly lower values of esr, have been made after lightly tinning the terminal pads of the capacitor. This puts a shallow meniscus on the surfaces, which if carefully filed, will provide a flat area on each pad and an intimate contact to the line. The pliancy of the solder will also allow it to yield to any minor irregularities on the surfaces of the contact discs to assure a good electrical connection.

With the component in position, the quality of the connection may be checked as follows:

a. Adjust the frequency of the signal generator to a proper resonant peak in the frequency band of interest (Paragraph 4.2.2.a and Figures 4-1 through 4-5).

b. Set the output level controls of the generator for a reading of 3 mV on the rf millivoltmeter.

c. The final adjustments for a peak reading should be made with the vernier controls for both frequency and output level.

d. After peaking the system, gently apply some additional pressure to the ferrule clamp and observe the indication on the rf millivoltmeter. If the original connection was good, there should be little or no change in the reading. If the reading changes by more than, say, 1%, a readjustment of the clamp, and the frequency and level, may be necessary.

4.2.1 MODEL 34A-01 (OPTION FOR SWALLOWING LEADS OF SERIES CONNECTED COMPONENTS)

The insertion of an axially leaded capacitor between the contact discs of the line requires that the leads be placed in the two channels provided: one in the center conductor of the line, and the other in the movable plunger. Contact is made directly at the terminal pads of the capacitor to exclude the leads from the measurement.

Unless the leads of the capacitor are quite short, installation of a leaded capacitor will require removal of the plunger and threaded ferrule clamp. With one lead inserted into the slot in the plunger (and covered by the clamp), the plunger and clamp should be positioned for remounting in the bushing. The slot in the plunger, holding the capacitor, must be aligned

with the slot in the center conductor. The plunger should then be moved into the line with the exposed lead entering the slot in the center conductor. Maintain pressure and the position of the plunger while tightening the threaded clamp.

When measuring unleaded components that are physically small, i.e., 50 and 100 mil cubes, they should be positioned below or to either side of the slots to avoid loss of contact surface. Larger capacitors may be centrally positioned to bridge the slots, but if there is doubt as to the effect of the slots, measurements should be made with the capacitor in various positions to determine the extent of the influence.

4.2.2 SERIES MEASUREMENT OF LOSS

With the test capacitor securely fastened in the fixture, a frequency search with the signal generator in the vicinity of a number of suitable test frequencies, as determined with the aid of the charts of Figures 4-1 through 4-5, will establish resonance in the system. Q_m, the Q-factor of the system, is measured as follows:

a. Adjust the signal generator frequency to a proper resonant frequency in the band of interest. Above 520 MHz, the Model 102-1A Frequency Doubler can be used to multiply the output frequency by 2, and by 4. The resonant frequencies of the system, for a given test capacitance, should be known through use of the charts referenced above in order to avoid confusion as to whether the resonant frequency is multiplied by 2 or by 4. For measurements above 1 GHz we recommend the use of a high-pass, or band-pass, filter to prevent interference from a resonance at a lower frequency.

b. Set the output level controls of the generator for a reading of 3.0 mV on the rf millivoltmeter.

c. The final adjustments for a peak reading should be made with the vernier controls for both frequency and output level.

d. Adjust the frequency of the signal generator above resonance until the rf millivoltmeter reading decreases to approximately 1.5 mV. Lock the generator output frequency by engaging the LOCK pushbutton. The upper VERNIER control should be adjusted for a reading of exactly 1.5 mV and the displayed frequency (set for a maximum resolution of 100 Hz) should be noted, or entered into a programmed calculator. This frequency is f_a.

e. Unlock the VFO and lower the frequency to a point below resonance where the rf millivoltmeter again reads about 1.5 mV. The phase-lock circuitry may be re-engaged and the output frequency that gives a meter reading of exactly 1.5 mV should be recorded, or entered in the calculator. This frequency is f_b.

The measurement frequency of f_1 is accurately determined by taking the arithmetic mean of f_a and f_b.

$$f_1 = (f_a + f_b)/2 \tag{4-1}$$

The measured Q-factor of the system is calculated from the measured values of f_1, f_a, and f_b.

$$Q_m = \sqrt{3} f_1/\Delta f = \sqrt{3} f_1/(f_a - f_b) \tag{4-2}$$

The Q-factor of the transmission line at the measurement frequency of f_1 is Q_1', and this is found directly from the value of Q_o' at f_o', and the exponent x' which defines the slope of Q vs. f on a log-log plot. Q_o' and x' are given on the calibration card supplied with the Model 34A (inside the cover of the storage case).

$$Q_1' = Q_o'(f_1/f_o')^{x'} \tag{4-3}$$

For the most accurate calculations of capacitance, and other related parameters such as the series inductance and self-resonant frequency (srf) of the capacitor, f_o' should be determined for each differently configured capacitor (see Paragraph 4.3). Satisfactory measurements can be made for two popular monolithic chip capacitors of cubic construction, however, using a simple empirically developed rule:

For 100 mil cubes, $f_o' = f_o - 0.3$ MHz
For 50 mil cubes, $f_o' = f_o - 0.4$ MHz

where f_o is the $\lambda/4$ resonant frequency of the line, as given on the calibration card.

The given value of Q_o' is for the frequency of f_o. Once the value of f_o' is determined for the capacitor under test, a slightly better value for Q_o' may be calculated. While it would appear that there is an anomaly with two values of Q_o', the difference will be usually less than one or two-tenths of a percent, and its influence on the measurement is small, and well within the accuracy class of the instrument. Nevertheless, a correction can be made.

$$\text{Corrected value of } Q_o' = (f_o'/f_o)^{x'} Q_o'(\text{calib})$$

An example will show the extent of the error that obtains by using the given value of Q_o' in lieu of the corrected value. The parameters of a line are given as: $f_o = 129.8$ MHz, $Q_o' = 1300$, and $x' = 0.45$. Measurements are to be made on a 50 mil chip capacitor, and using the empirical rule, $f_o' = 129.8 - 0.4 = 129.4$ MHz. The corrected value of $Q_o' = 1300(129.4/129.8)^{0.45} = 1298.2$. This is 0.14% less than the given value of 1300.

A capacitor measured with this line yields half-voltage frequencies of 420.2708 and 419.7327 MHz. With a fixture resistance of 4 milliohms, and $Q_o' = 1300$, the capacitor parameters are: C = 12.3 pF, esr = 61.3 mΩ, and Q = 502.2. If $Q_o' = 1298.2$, the parameters are: C = 12.3 pF, esr = 61.2 mΩ, and Q = 503.4. The difference in loss is about 0.25%.

Instead of making the correction in the manner just described, the correct value of Q_1' will also result by using f_o in (4-3). We suggest that this is unnecessary because the program for the calculator will then require an entry of both f_o and f_o', whereas the value of f_o' needed for valid calculations of capacitance has been shown to be quite satisfactory for Q_1'.

Having determined values for f_1, Q_m, f_o', and Q_1', the esr of the test capacitor may be found from:

$$ESR = Z_o[(\pi/4)(f_1/f_o')\csc^2(f_1/f_o')90^o - 0.5\cot(f_1/f_o')90^o][(1/Q_m) - (1/Q_1')] - r_f \ (\Omega) \qquad (4\text{-}4)$$

where $Z_o = 75.75$ ohms

and r_f is found from (6-6) (see Section VI)

4.2.3 CAPACITANCE

With f_1 established, the capacitance may be found from:

$$C = -1/\omega_1 Z_o \cot\beta_1 \ell \qquad (3\text{-}3)$$

$$\text{where } \beta_1 \ell = (f_1/f_o')90^o \qquad (3\text{-}4)$$

The correct value of f_o' assumes its importance in (3-4). Too large a value will assign excessive inductance to the capacitor, and the capacitance will show an inordinate rise with frequency. Too low a value will effectively negate some, or all, of the self inductance of the device, and it will show a constancy, or even a decrease of capacitance with increasing frequency, which is unrealistic. A complete description of the measurement for f_o' may be found in Paragraph 4.3.

4.2.4 Q-FACTOR

When the capacitance is known, the Q-factor may be found by taking the ratio of the reactance to effective series resistance.

$$Q = 1/\omega_1 Cr \qquad (4\text{-}5)$$

where r = esr from (4-4)

It should be noted that if the measurement frequency is greater than the self resonant frequency of the test capacitor, the capacitance will be negative, and its reactance will be

that of the equivalent inductance of the device. In writing a calculator program, however, unless this negative capacitance is recognized, the calculated Q-factor will be negative, which is meaningless for a two-terminal measurement. In the program listed in Section VII , the capacitance is tested for polarity and negative values are printed to alert the user, and the calculator then prints the equivalent inductance of the test device, in nanohenries.

Note that this is the equivalent inductance and it includes the effect of the capacitive reactance. Near self resonance, for example, this equivalent inductance will be quite small, and will equal zero at resonance. The actual series inductance can be found with (4-11). For very large values of capacitance at high frequencies (well above the self resonant frequency), these two are sensibly equal.

4.3 f_o' AND DISCONTINUITY INDUCTANCE, L_d

The insertion of a series capacitor in the center conductor of the Model 34A generally causes a step down of the effective diameter of the conductor for the length of the capacitor. This abrupt discontinuity has been shown by Whinnery and Jamieson [1] to be equivalent to adding series inductance to the line at the points of the discontinuities. To ignore this, and falsely attribute it to the capacitor, burdens the capacitor with unwarranted inductance.

To find the correct value of f_o' for a given capacitor configuration, measure the total effective inductance of a dummy capacitor, which consists of a solid conductor with the same length and the same cross sectional dimensions as the terminal pads of the capacitor. Brass is a convenient material for forming the dummy capacitor.

The dummy capacitor will resonate in the line at a frequency just below f_o. The electrical length of the line equals $\beta'\ell$, and

$$\beta'\ell = (f'/f_o)90^\circ \qquad (4\text{-}6)$$

where f' = the lowest resonant frequency of the line with the dummy capacitor installed, and

f_o = the quarter-wavelength frequency of the short-circuited line.

[1] J. R. Whinnery & H. W. Jamieson, "Equivalent Circuits for Discontinuities in Transmission Lines", Proc. I.R.E., Vol. 32, No. 2, Feb. 1944.

The total inductive reactance of the dummy capacitor and discontinuity is:

$$\omega' L_t = Z_o \cot(\beta' \ell) \tag{4-7}$$

where $\omega' = 2\pi f'$

The inductance of a conductor of rectangular cross section is given by Grover [1] as:

$$L = 2\ell[\log_e 2\ell/(h + w) + 0.5] \quad \text{(nH)} \tag{4-8}$$

where ℓ is the length, w is the width, and h is the height, and all dimensions are in centimeters.

The discontinuity inductance is:

$$L_d = L_t - L \tag{4-9}$$

At frequencies close to f_o, the added series inductance that causes a small decrease in the resonant frequency is sensibly linear with frequency, and f_o' may be proportioned from L_t, L, L_d, and f'.

$$f_o' = (L/L_t)\Delta f' + f' \tag{4-10a}$$

or,

$$f_o' = f_o - (L_d/L_t)\Delta f' \tag{4-10b}$$

where $\Delta f' = f_o - f'$

and, f_o = short-circuited $\lambda/4$ frequency

f' = lowest resonant frequency of line with dummy capacitor installed

L_t = total inductance of dummy capacitor and discontinuity inductance, from (4-7)

L = inductance of dummy capacitor, from (4-8)

L_d = discontinuity inductance, from (4-9)

4.4 EXAMPLE MEASUREMENT - SERIES MODE

A Model 34A Resonant Coaxial-Line has the following calibrated data:

[1] F. W. Grover, "Inductance Calculations", D. Van Nostrand Co., Inc., New York, 1946.

SERIES	SHUNT
$Q_o' = 1309$	$Q_o = 1200$
$r_f = 0.0041\ \Omega$	$f_o = 129.8$ MHz
$x' = 0.444$	$x = 0.443$

A monolithic chip capacitor of 82 pF (nominal value) is to be measured. A cube of brass whose dimensions equal those of the capacitor (very nearly) is installed in series with the line, and the system resonates at $f' = 129.1042$ MHz.

$$\beta'\ell = (129.1042/129.8)90^\circ \qquad (4\text{-}6)$$
$$= 89.51755^\circ$$

The total reactance added to the line is:

$$\omega'L_t = 75.75 \cot(89.51755^\circ) \qquad (4\text{-}7)$$
$$= 0.6379\ \Omega$$

The dimensions of the dummy capacitor are $\ell = 0.310$ cm, $h = 0.305$ cm, and $w = 0.183$ cm. The calculated inductance is:

$$L = 2(0.31)[\log_e(0.62/0.488) + 0.5] \qquad (4\text{-}8)$$
$$= 0.458\ \text{nH}$$

and,

$$L_d = 0.786 - 0.458 \qquad (4\text{-}9)$$
$$= 0.328\ \text{nH}$$

From the information just assembled, we can find f_o':

$$f_o' = (0.458/0.786)(129.8 - 129.1) + 129.1 \qquad (4\text{-}10a)$$
$$= 129.5\ \text{MHz}$$

or,

$$= 129.8 - (0.328/0.786)(0.7) \qquad (4\text{-}10b)$$
$$= 129.5\ \text{MHz}$$

With the test capacitor of 82 pF connected in series with the line, the first frequency of resonance above f_o is at approximately 143 MHz. The two frequencies representing the half-voltage points are:

$$f_a = 143.3565 \text{ MHz}$$
$$f_b = 143.0115 \text{ MHz}$$

from these,

$$f_1 = 143.18 \text{ MHz} \quad (4\text{-}1)$$
$$Q_m = 718.8 \quad (4\text{-}2)$$

and,

$$Q_1' = 1368.7 \quad (4\text{-}3)$$

Using these data in (4-4):

$$(\pi/4)(f_1/f_o')\csc^2(f_1/f_o')90^\circ = (3.1416/4)(143.18/129.5)\csc^2(143.18/129.5)90^\circ$$
$$= 0.8927$$
$$0.5\cot(f_1/f_o')90^\circ = 0.5\cot(143.18/129.5)90^\circ$$
$$= -0.08376$$
$$(1/Q_m) - (1/Q_m') = (1/718.8) - (1/1368.7)$$
$$= 0.0006606$$
$$\text{and, } Z_o = 75.75 \text{ ohms}$$

Combining terms,

$$ESR = 75.75(0.8927 + 0.08376)(0.0006606) - r_f \quad (4\text{-}4)$$
$$= 0.04886\ \Omega - r_f$$

The fixture resistance, r_f, as described in Section VI, is derived from the Q-factors of the line for both open and short circuit conditions, and x'. It can be shown that,

$$r_f = r_{f_\theta}(f_1/f_o')^{(1 - x')} \quad (6\text{-}6)$$

For this example,

$$r_f = 0.0041(143.18/129.5)^{0.556} \quad (6\text{-}6)$$
$$= 0.00434\ \Omega$$

The esr for the capacitor in this example is, therefore:

$$ESR = 0.04886 - 0.00434 = 0.0445\ \Omega$$

The effective capacitance at the measurement frequency is:

$$C = -1/(7.283 \times 143.18 \times 10^6 \times 75.75 \times \cot 99.5073^\circ) \quad (3\text{-}3)$$
$$= 87.62 \text{ pF}$$

The reactance of the capacitor is -j12.69 Ω, and it follows that the Q-factor is:

$$Q = 12.69/0.0445 = 285 \quad (4\text{-}5)$$

4.5 SERIES INDUCTANCE

The effective reactance of a capacitor with series inductance decreases more rapidly with frequency than a pure capacitor, whose reactance varies as 1/f. The net reactance of a capacitor with inductance passes through zero at the self-resonant frequency, and is inductive at higher frequencies.

To obtain system resonance above the self-resonant frequency of a test specimen, the line must present capacitive reactance. This occurs at frequencies below $\lambda/4$, and between even half-wavelengths and the next shorter odd quarter-wavelength. A series-connected capacitor is inductive if it resonates with the Model 34A below 130 MHz, or between 260 and 390 MHz, 520 and 650 MHz, 780 and 910 MHz, and 1040 and 1170 MHz. These are approximate values based upon a $\lambda/4$ frequency of 130 MHz.

The influence of the self inductance of a capacitor can be noted in the departure of successive resonant frequencies from the ideal. For example, an 82 pF capacitor, without inductance, should resonate in a typical Model 34A line at 144.02, 393.86, and 650.75 MHz (f_o' = 129.5 MHz). Actually, resonances occurred at 143.18, 391.69, and 647.08 MHz, indicating the device is capacitive at the two lower frequencies, and inductive at 647 MHz.

4.6 MEASURING SERIES INDUCTANCE

Assuming the presence of only capacitance and series inductance, we can make use of measured data taken at two frequencies, not necessarily successive, to find the series inductance of the capacitor. The inductance is:

$$L = (f_2X_2 - f_1X_1)/2\pi(f_2^2 - f_1^2) \quad (\mu H) \qquad (4\text{-}11)$$

where $f_2 > f_1$, and f is in MHz.

$$\text{and } X = Z_o \cot[(f/f_o')90^\circ] \quad (\Omega) \qquad (4\text{-}12)$$

The subscripts for f and X must match in (4-12), and in (4-11) L is in μH when f_1 and f_2 are in MHz. The sign of the reactance derived from (4-12) should reflect the nature of the test component at that frequency. If the device is capacitive, the sign should be negative, and positive if it is inductive.

From the data of Paragraph 4.5, let f_2 = 391.69 MHz, and f_1 = 143.18 MHz. At f_1,

$$X_1 = 75.75 \cot[(143.18/129.5)90^\circ] \qquad (4\text{-}12)$$
$$= -12.686\ \Omega$$

At f_2,

$$X_2 = -2.933\ \Omega \tag{4-12}$$

and,

$$L = \frac{-1148.637 + 1816.406}{6.2832 \times 132920.544} = 0.000800\ \mu H \tag{4-11}$$

This is the self inductance of the capacitor. The low frequency (1 MHz) capacitance may be found either by measurement, or from:

$$C = C_e/(1 + \omega^2 L C_e) \tag{4-13}$$

The effective capacitance at 143.18 MHz (see Paragraph 4.4) = 87.62 pF. From this:

$$C = 87.62/(1 + 39.478 \times 143.18^2 \times 10^{12} \times 0.8 \times 87.62 \times 10^{-21}) \tag{4-13}$$
$$= 82.92\ pF$$

At 1 MHz this capacitor measured 82.84 pF, which is within 0.1% of the calculated value. The self resonant frequency may be calculated from the usual equation.

$$f_r = 1/2\pi\sqrt{LC} = 1/6.2832\sqrt{0.8 \times 82.84 \times 10^{-21}} \tag{4-14}$$
$$= 618.2\ MHz$$

4.7 ESR FOR LARGE CAPACITANCE

The effective series resistance of by-pass, blocking, and other high-capacitance devices can be measured at high frequencies in the series mode with the Model 34A, provided they can be installed in the series fixture. These capacitors are normally self resonant at relatively low frequencies, and inductive at higher frequencies.

The esr can be determined with (4-4), and the series inductance may be found from two measurements and (4-11).

Because the series inductance of capacitors of this type is usually a few nanohenries, or less, the system resonances will occur near the odd quarter-wavelength frequencies, i.e., 130, 390, 650 MHz, etc. If the esr of the device must be known at some intermediate frequency, measurements should be made straddling the frequency of interest, and the esr can be interpolated. If there is doubt as to the constancy of the esr slope, at least three measurements should be made.

The accuracy of esr measurements for capacitors of this type is good, but the evaluation of the equivalent inductance at any particular frequency, or the series inductance of the device,

which is dependent upon two measurements, is subject to errors of a few percent owing to the extremely low reactances encountered. Because the capacitive reactance has virtually disappeared at these frequencies, the equivalent inductance will approximate the series inductance of the capacitor.

4.8 HIGH FREQUENCY SERIES MODE MEASUREMENTS

At frequencies in the order of 600 MHz, and above, there is evidence of radiation, as indicated by hand effects on the outer surfaces of the coaxial line, as well as a lowering of the Q-factor of the line from the expected straight-line projection. Radiation, of course, represents a power loss, and unless it is eliminated, calculations based upon a linear extension of the Q-factor of the line with frequency (on a log-log plot), will be in error.

Radiation can be virtually eliminated with a simple hollow conducting-pipe, attached to and continuing the outer conductor at the open end of the line. It acts to terminate the line in a way that prevents spillage of flux, thereby confining energy to the line. The hollow pipe is a waveguide below cut-off, and is designated Model 34-2A, Cut-Off Attenuator, supplied with the Model 34A.

When it is necessary to define the parameters of a capacitor over a wide range of frequencies, a more accurate evaluation will obtain if the measurements can be made with the Model 34-2A Cut-Off Attenuator installed, especially for specimens whose Q-factor are greater than, say, 200.

For measurements above 600 or 700 MHz, it is also necessary to replace the Model 91-12F RF Millivoltmeter Probe with a special high impedance probe, Model 34-1A. The input resistance of the 91-12F probe decreases with frequency (12 dB per octave), and at high frequencies introduces sufficient loss to cause the Q-factor of the line to depart from values projected by (4-3). The Model 34-1A may be used to beyond 1250 MHz.

4.9 LOW Q-FACTORS

The rf millivoltmeter is coupled close to a point of maximum voltage when the line is resonant, either unloaded or loaded with a test capacitor. The line voltage at the coupled point must be sufficient to provide a suitable reading on the rf millivoltmeter, which preferably should be on a range no lower than 3 mV, f.s. Use of the 1 mV range may at times be necessary, but it is less satisfactory than other ranges owing to the meter unrest below full scale.

The voltage at the end of the line, however, is a function of the Q-factor of the system, and when measuring low Q specimens the Q-factor of the system will be correspondingly low. This

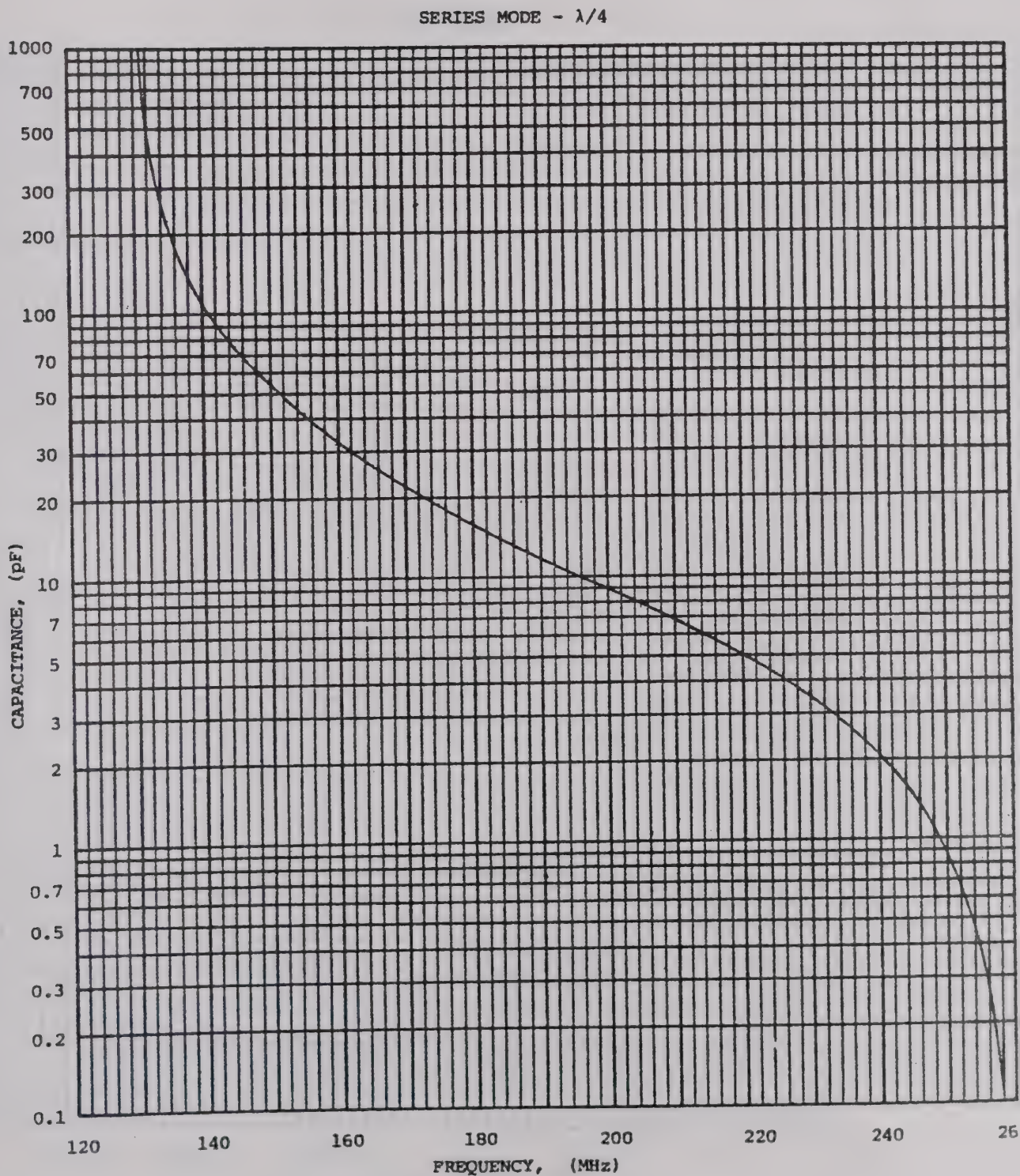
SERIES MODE - λ/4
1000
700
500
300
200
100
70
50
30
20
10
7
5
3
2
1
0.7
0.5
0.3
0.2
0.1
CAPACITANCE, (pF)
120
140
160
180
200
220
240
26
FREQUENCY, (MHz)

Figure 4-1

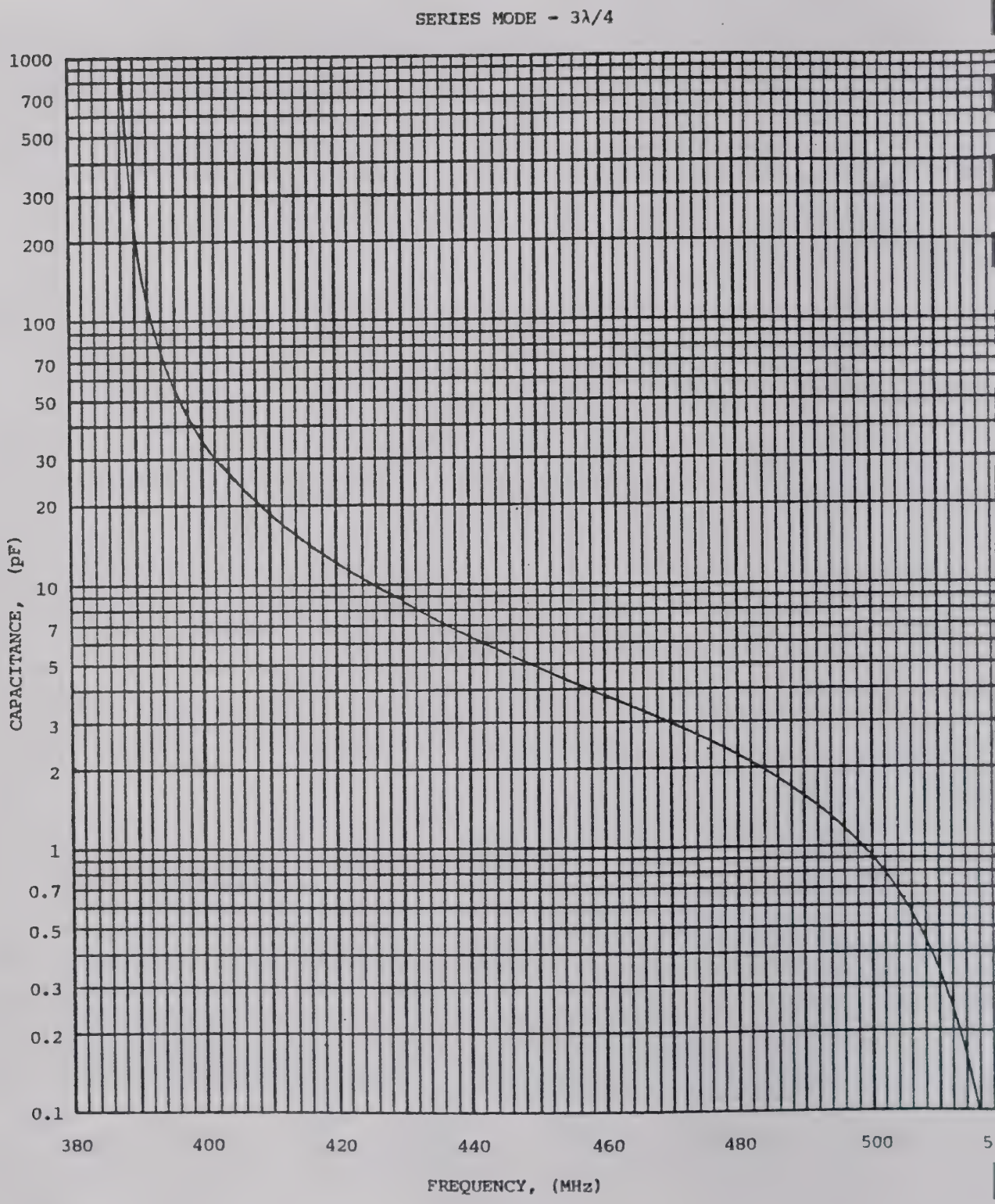
SERIES MODE - 3λ/4
1000
700
500
300
200
100
70
50
30
20
10
7
5
3
2
1
0.7
0.5
0.3
0.2
0.1
CAPACITANCE, (pF)
380
400
420
440
460
480
500
FREQUENCY, (MHz)

Figure 4-2

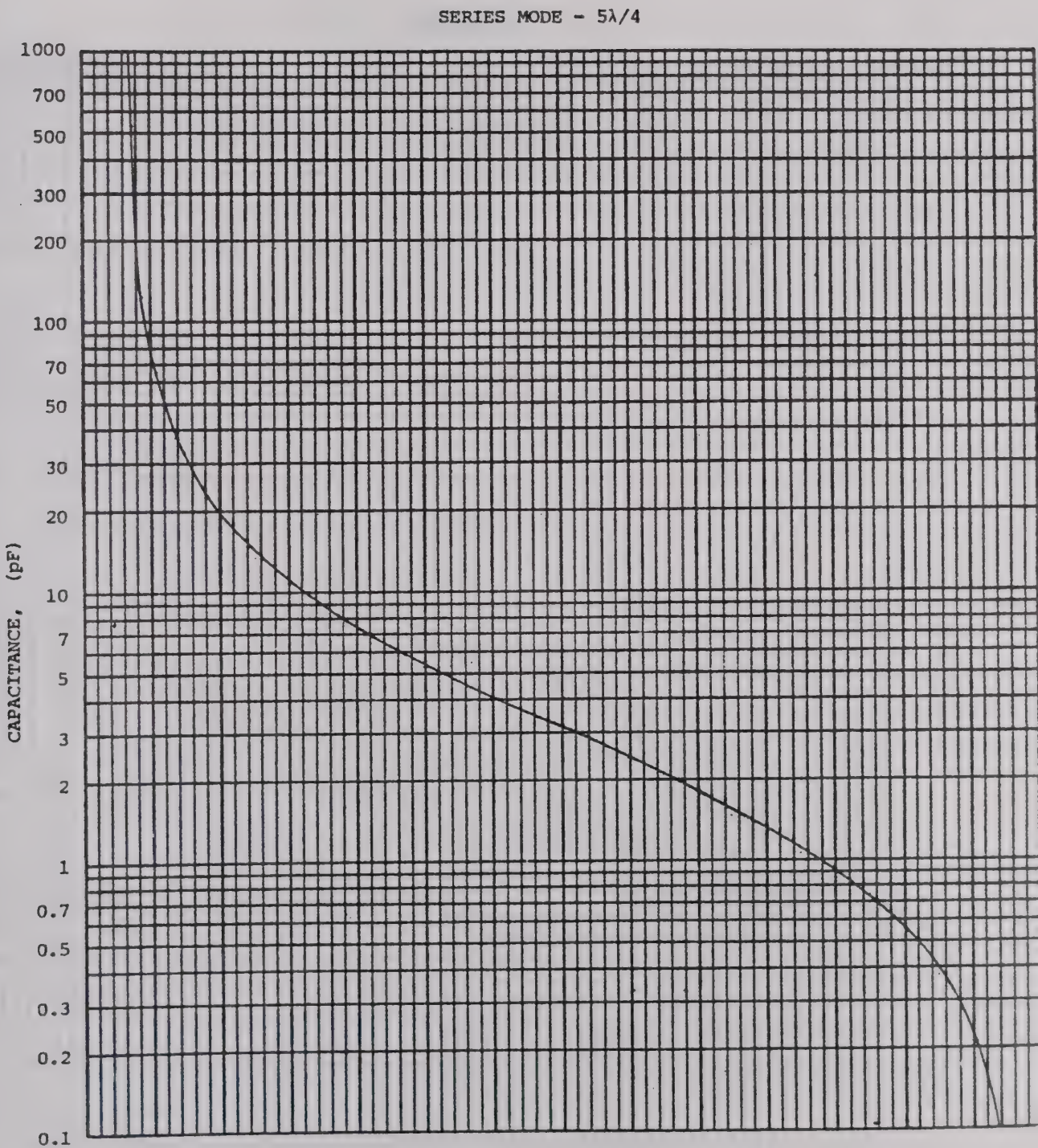
SERIES MODE - 5λ/4
1000
700
500
300
200
100
70
50
30
20
10
7
5
3
2
1
0.7
0.5
0.3
0.2
0.1
CAPACITANCE, (pF)
640
660
680
700
720
740
760
FREQUENCY, (MHz)

Figure 4-3

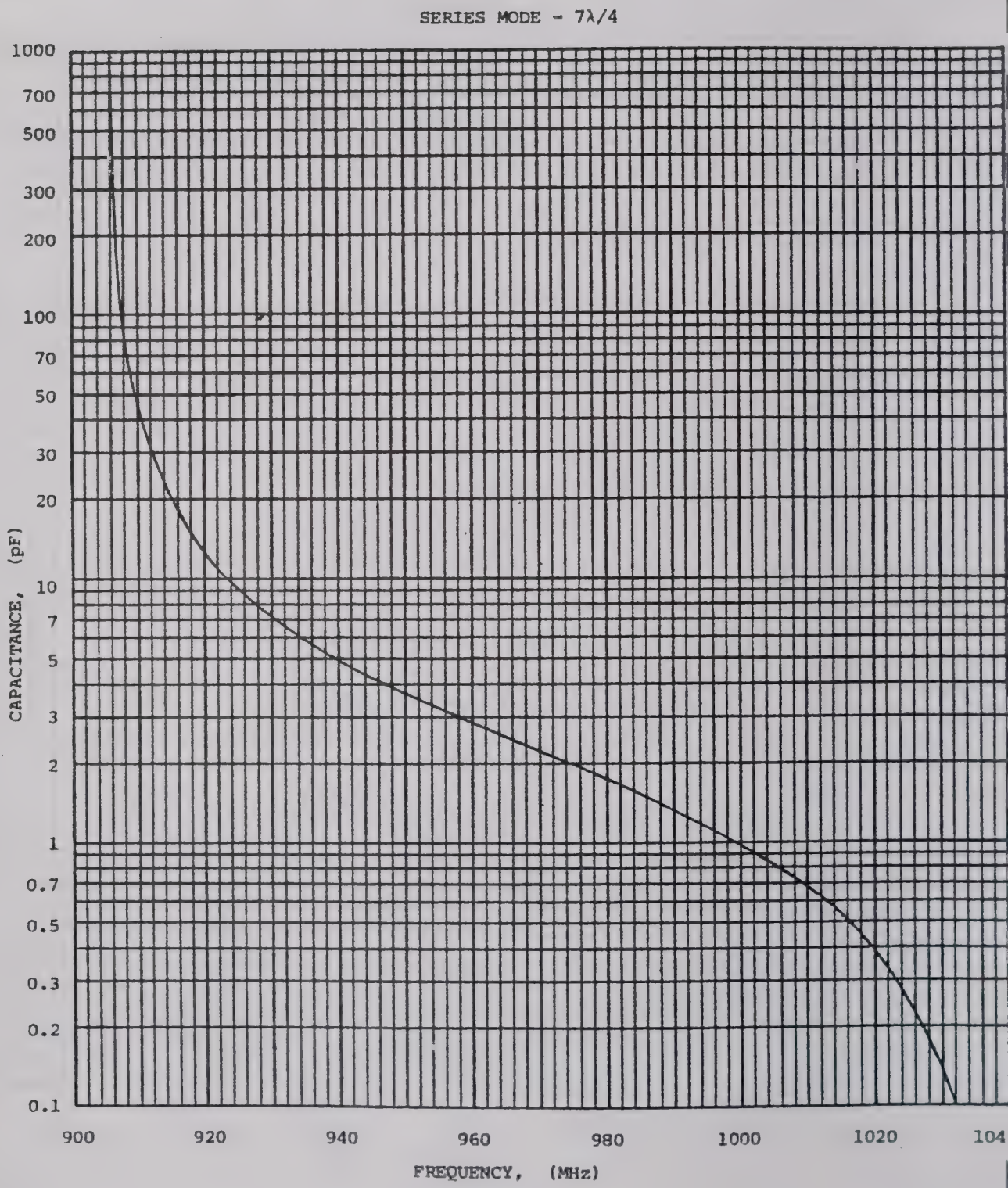
SERIES MODE - 7λ/4
1000
700
500
300
200
100
70
50
30
20
10
7
5
3
2
1
0.7
0.5
0.3
0.2
0.1
CAPACITANCE, (pF)
900
920
940
960
980
1000
1020
104
FREQUENCY, (MHz)

Figure 4-4

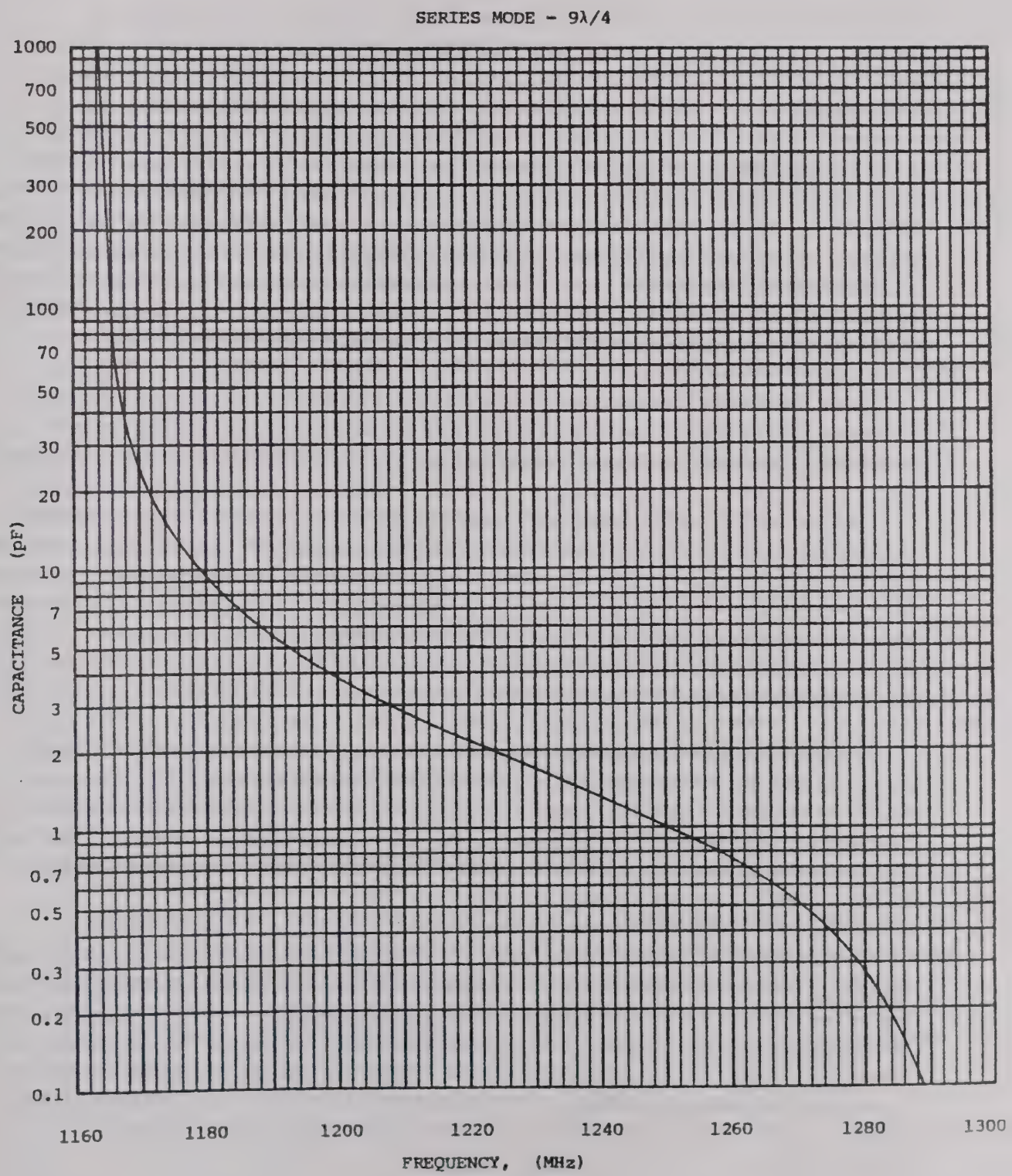
SERIES MODE - 9λ/4
1000
700
500
300
200
100
70
50
30
20
10
7
5
3
2
1
0.7
0.5
0.3
0.2
0.1
CAPACITANCE (pF)
1160
1180
1200
1220
1240
1260
1280
1300
FREQUENCY, (MHz)

Figure 4-5

SECTION V

SHUNT MODE MEASUREMENT OF CAPACITORS

5.1 GENERAL

Shunt measurements of capacitors are made by connecting a test capacitor across the open-circuited end of the transmission line with a proper short circuit established at the other end of the line. The test capacitor is connected between the center conductor and the outer wall of the line. Connecting clamps are provided at both points of contact: at the center conductor the coin silver jaws are opened and closed with an Allen head screw and driver, and the wall clamp is plated to prevent oxidation from affecting the resistance of the connection. The plating is sufficiently thin so as not to contribute materially to the total resistance.

Shunt measurements are particularly well suited for capacitors whose connecting means, or dimensions, preclude their insertion in series with the line. This includes some variable ceramic, air, or piston capacitors, as well as small radial leaded ceramic and mica capacitors.

An advantage of the shunt mode measurement is evident when the actual circuit environment requires finite lead lengths. If the condition can be duplicated with a shunt connection to the line, the measured parameters should closely approximate those of the component under operating conditions. A plot of the parameters for two or three measurement frequencies may be needed to show the properties of the component at the circuit frequency.

5.2 SHORT-CIRCUITED LINE

A short circuit at the closed end of the line is established by inserting the movable plunger to meet the center conductor, and the threaded ferrule clamp should be tightened to secure the plunger and provide a pressure contact. The two contacting surfaces are machined from coin silver. This material is a good conductor, and is resistant to oxidation. The two surfaces should be parallel, and when in contact and under pressure, the resistance should be low and repeatable for each mating.

The Q-factor that obtains for the short-circuited, unloaded condition, is Q_o. The measurement of Q_o is described in Section VI. The magnitude of Q_o is a function, principally, of the series resistance of the coaxial line; the contact resistance of the plunger should make a minor contribution. The extent to which this is true is manifest in the measured value of Q_o, which should agree closely with the value given on the calibration card for the Model 34A. The constancy of Q_o for successive matings of the two surfaces is a measure of the efficacy of the contact.

When setting up the line for shunt mode measurements, assurance of a good contact can be had without repeated calculations of Q_o by simply noting the amplitude of the peak resonant response for each pressure contact. If the rf millivoltmeter does not respond to very nearly the same indicated value for each complete mating of the two surfaces, say, within ±2%, with only minor adjustment for frequency, it is likely that some irregularity exists on one or both surfaces which will influence the measurement of Q_o, and, more importantly, the accuracy of shunt mode measurements.

Minor irregularities on the surfaces of the contacting discs are usually negated by the insertion of a thin square of soft copper, about 5/16" on a side, placed between the discs. The pliant copper foil will yield to slight irregularities and provide a good low resistance path across the junction. Several squares of copper foil are supplied with the Model 34A for this purpose. It is *important* that both surfaces of the copper foil be *cleaned thoroughly* just before using to remove the oxide which forms quickly on exposed copper surfaces.

For all shunt mode measurements, the closed end of the Model 34A Resonant Coaxial-Line must be shorted with the movable plunger and threaded ferrule clamp. The copper foil, if needed, should remain in place during the measurement period. If the period is an extended one, Q_o should be checked before each measurement session to determine that oxidation of the copper has not affected the performance of the line.

If the coin silver surfaces of the contact discs mate sufficiently well so as not to require the additional copper foil, still, an occasional measurement of Q_o is recommended. While coin silver is slow to oxidize, some environments may hasten the process, and a silver oxide or sulphide will develop on the surfaces. Periodic cleaning of the discs and the threads of the ferrule clamp and bushing with a good silver polish will assure repeatable performance of the system. A small soft brush and cotton swabs are useful for this. The contact surfaces may also be cleaned with a pencil eraser.

5.3 SHUNT MODE MEASUREMENTS OF CAPACITORS

When the closed end of the line has been properly short circuited, and with the test component securely fastened in place, resonance of the system can be found with the aid of Figures 5-3 through 5-7. Q_m, the Q-factor of the system, is measured as follows:

a. In the frequency band of interest, adjust the frequency of the signal generator for a proper resonant peak.

b. Set the output controls of the generator for a reading of 3.0 mV on the rf millivoltmeter.

c. The final adjustments for a peak reading should be made with the vernier controls for both frequency and output level.

d. Adjust the frequency of the signal generator above resonance until the rf millivoltmeter reading decreases to approximately 1.5 mV. Lock the generator output frequency by engaging the LOCK pushbutton. The upper VERNIER control should be adjusted for a millivoltmeter reading of exactly 1.5 mV and the displayed frequency (set for a maximum resolution of 100 Hz) should be noted, or entered into a programmed calculator. This frequency is f_a.

e. Unlock the VFO and lower the frequency to a point below resonance where the rf millivoltmeter again reads about 1.5 mV. The phase-lock circuitry may be re-engaged, and the output frequency that gives a meter reading of exactly 1.5 mV should be recorded, or entered in the calculator. This frequency is f_b.

The measurement frequency of f_1 is accurately determined by taking the arithmetic mean of f_a and f_b.

$$f_1 = (f_a + f_b)/2 \tag{4-1}$$

The measured Q-factor of the system is calculated from the measured values of f_1, f_a, and f_b.

$$Q_m = \sqrt{3} f_1/\Delta f = \sqrt{3} f_1/(f_a - f_b) \tag{4-2}$$

The Q-factor of the line at the measurement frequency of f_1 is also needed, and this is found directly from the value of Q_o at f_o, and the exponent x which defines the slope of Q vs. f on a log-log plot. Q_o, f_o, and x are given on the calibration chart supplied with the Model 34A (inside the storage case).

$$Q_1 = Q_o(f_1/f_o)^x \tag{5-1}$$

Details of the measurement of Q_o and x are given in Section VI.

The parameters of the test capacitor are calculated from the following equations:

$$ESR = Z_o[(\pi/4)(f_1/f_o)\ \sec^2(f_1/f_o)90^o + 0.5\ \tan(f_1/f_o)90^o][(1/Q_m) - (1/Q_1)]\ (\Omega) \tag{5-2}$$

where $Z_o = 75.75$ ohms

The Q-factor of the capacitor may then be found from:

$$Q = 1/\omega_1 Cr \qquad (5\text{-}3)$$

where C is given by (3-1), and r is the effective series resistance (ESR), as given by (5-2).

5.4 EXAMPLE MEASUREMENT - SHUNT MODE

A Model 34A was characterized as having the following parameters:

$$f_o = 129.8 \text{ MHz}$$
$$Q_o = 1200$$
$$x = 0.444$$

A 22 pF monolithic ceramic capacitor with axial ribbon-leads was connected across the open end of the line, and the two half-voltage frequencies were measured:

$$f_a = 74.1420 \text{ MHz}$$
$$f_b = 73.8580 \text{ MHz}$$

These calculations follow:

$$f_1 = (74.1420 + 73.8580)/2 = 74.000 \text{ MHz} \qquad (4\text{-}1)$$

$$Q_m = \sqrt{3} \times 74.0/(74.1420 - 73.8580) = 451.31 \qquad (4\text{-}2)$$

$$Q_1 = 1200(74.0/129.8)^{0.444} = 935.0 \qquad (5\text{-}1)$$

$$(\pi/4)(f_1/f_o) = 0.7854 \times 0.5701 = 0.4478$$

$$\sec^2(f_1/f_o)90^o = \sec^2 51.3097^o = 2.5591$$

$$\tan(f_1/f_o)90^o = \tan 51.3097^o = 1.2486$$

$$ESR = 75.75(0.4478 \times 2.5591 + 0.5 \times 1.2486)[(1/451.31) - (1/935.0)] \qquad (5\text{-}2)$$

$$ESR = 0.1537\ \Omega$$

$$C = 1/6.2832 \times 74.0 \times 10^6 \times 75.75 \times 1.2486 = 22.74 \text{ pF} \qquad (3\text{-}1)$$

$$Q = 1/6.2832 \times 74.0 \times 10^6 \times 22.74 \times 10^{-12} \times 0.1537 = 615.3 \qquad (5\text{-}3)$$

5.5 HIGH FREQUENCY SHUNT MODE MEASUREMENTS

At frequencies in the order of 600 MHz, and above, there is evidence of radiation, as indicated by hand effects on the outer surface of the coaxial line, as well as a lowering of the Q-factor of the line from the expected straight-line projection. Radiation, of course, represents a power loss, and unless it is eliminated, calculations based upon a linear extension of the Q-factor of the line with frequency (on a log-log plot), will be in error.

Radiation can be virtually eliminated with a simple hollow conducting-pipe, attached to and continuing the outer conductor at the open end of the line. It acts to terminate the line in a way that prevents spillage of flux, thereby confining energy to the line, and the test capacitor. The hollow pipe is a waveguide below cut-off, and is designated Model 34-2A, Cut-Off Attenuator, supplied with the Model 34A.

When it is necessary to define the parameters of a capacitor over a wide range of frequencies, a more accurate evaluation will obtain if the measurements can be made with the Model 34-2A Cut-Off Attenuator installed, especially for specimens whose Q-factor are greater than, say, 200.

Provided the dimensions and leads will permit the test component to be mounted within the shield, the connection is simple. After connecting one lead to the center conductor, the wall clamp is removed and as the shield is installed, it will clamp the other lead to the outer conductor. Any lead, other than a thin ribbon, should be flattened to prevent a gap between the end of the outer tube of the Model 34A and the Model 34-2A Cut-Off Attenuator. A better technique is to machine a flat, or half-round, groove at the mating end of the Cut-Off Attenuator and collar. For good clamping, the dimension of the groove should be somewhat less than the lead dimension.

For measurements above 600 or 700 MHz, it is also necessary to replace the Model 91-12F RF Millivoltmeter Probe with a special high impedance probe, Model 34-1A. The input resistance of the 91-12F probe decreases with frequency (12 dB per octave), and at high frequencies introduces sufficient loss to cause the Q-factor of the line to depart from values projected by (5-1). The Model 34-1A may be used to beyond 1250 MHz.

5.6 LOW Q-FACTORS

The rf millivoltmeter is coupled close to a point of maximum voltage when the line is resonant, either unloaded or loaded with a test capacitor. The line voltage at the coupled point must be sufficient to provide a suitable reading on the rf millivoltmeter, which preferably should be on a range no lower than 3 mV, f.s. Use of the 1 mV range may at times be necessary, but it is less satisfactory than other ranges owing to the meter unrest below full scale.

The voltage at the end of the line, however, is a function of the Q-factor of the system, and when measuring low Q specimens the Q-factor of the system will be correspondingly low. This will necessitate raising the output level of the generator, and may require use of the 1 mV range on the rf millivoltmeter unless the input coupling is increased.

The degree of coupling described in Paragraph 3.5 provides a good compromise between induced voltage and induced loss. Minimum coupled loss, however, is of concern only when measuring capacitors with medium to high Q-factors. If the Q-factor of the test capacitor is so low as to require switching to the 1 mV range, and a number of such measurements are to be made, in addition to using the full output level from the signal generator, the coupling loop may be rotated enough to furnish an rf millivoltmeter reading of 3 mV at resonance.

In some instances the rotation of the 50 ohm coupling loop to the same plane as the center conductor may not be sufficient to raise the level on the millivoltmeter to 3 mV. In such cases, and particularly at the lower frequencies, a one or two-turn loop can be installed on the spare TNC connector supplied with the Model 34A. This should be done only for test specimens that have low Q-factors, and a measurement of Q_o should be made after the modified coupling loop is installed, to determine the extent of the increase in reflected loss into the line.

This is covered in greater detail in Section VI. A slight reduction in the Q-factor of the line through coupled loss should not alter the measured Q-factor of the test capacitor by more than a few percent. If there is some doubt, the measurement may be compared with one taken with more normal coupling, using the rf millivoltmeter on the 1 mV range.

5.7 LEAD INDUCTANCE AND RESISTANCE

Owing to the inductance of the connecting leads for shunt mode measurements, the measured capacitance will be greater than the intrinsic capacitance of the test specimen by a factor related to the lead inductance. The relationship, ignoring the self inductance of the capacitor, is:

$$C_m = C/(1 - \omega^2 LC) \qquad (5\text{-}4)$$

where C_m = the measured capacitance (F)
C = the intrinsic capacitance of the specimen (F)
L = the lead inductance (H)
and $\omega/2\pi$ = the test frequency (Hz)

The resistance of the connecting leads will, of course, reduce the effective Q-factor of the overall specimen. The measured Q-factor is related to the capacitor parameters by:

$$Q_m = Q_c(1 - \omega^2 LC)/(1 + Q_c \omega C r_\ell) \qquad (5\text{-}5)$$

where Q_m = the measured Q-factor
Q_c = the Q-factor of the capacitor without leads

$\omega/2\pi$ = the test frequency, f_1 (Hz)

L = the lead inductance (H)

C = the intrinsic capacitance of the specimen (F)

r_ℓ = the effective resistance of the leads (Ω)

It should be noted that the presence of both lead inductance and resistance act to reduce the measured Q-factor below the Q-factor of the capacitor alone.

5.8 SERIES INDUCTANCE

The Model 34A system exhibits resonance for the shunt mode of operation when the transmission line presents a reactance equal in magnitude, but opposite in phase, to the effective reactance of the test capacitor. When this condition obtains, the voltage at the junction of the line and the test capacitor is maximum, and the rf millivoltmeter responds to this voltage.

The effective reactance of a capacitor with series inductance decreases more rapidly with frequency than a capacitor without inductance (whose reactance falls as 1/f). The reactance of a capacitor with inductance passes through zero at the self resonant frequency, and is inductive at higher frequencies.

It is possible, of course, to obtain system resonance above the self-resonant frequency of the test specimen. Under this condition the specimen is inductive and the line is capacitive. For the Model 34A line to present capacitive reactance when the other end is short-circuited, the operating frequency must fall between $\lambda/4$ and $\lambda/2$, $3\lambda/4$ and λ, or $5\lambda/4$ and $3\lambda/2$, etc. Thus, a shunt connected capacitor that resonates between 130 and 260 MHz, 390 and 520 MHz, or 650 and 780 MHz, etc., is inductive. These numbers are approximate and are based upon a $\lambda/4$ frequency of 130 MHz .

The influence of the lead and self inductance may be noted in the departure of successive resonant frequencies from the ideal. For example, a 120 pF capacitor (1 MHz measurement) when measured in the shunt mode on a line of f_o = 129.72 MHz should, for a pure capacitor, show resonant responses at 36.73, 264.9, and 521.7 MHz. Instead, resonance occurred at 36.2, 258.9, and 509.4 MHz.

Because the second resonant frequency was less than $2f_o$ ($\lambda/2$), and the third was below $4f_o$ (λ), it is evident that the device was inductive at those frequencies. Moreover, the second response was close to $2f_o$ which indicates the device was approaching resonance. Furthermore,

as would be expected, the rf millivoltmeter reading at this frequency was substantially lower than normal, which manifests a low impedance at the junction of the line and the test capacitor.

In the frequency domain of the 3/4 wavelength mode (260 to 390 MHz), the reactance of moderate to large values of capacitance is inherently low, and the presence of inductance further reduces the effective reactance and Q-factor, and abated by the lead resistance, the Q-factor of the system may be so low as to prevent the junction voltage from rising to a detectable level without excessive input coupling.

5.9 MEASURING SERIES INDUCTANCE

Assuming the presence of only the capacitance and series inductance, we can make use of measured data taken at two frequencies, not necessarily successive, to determine the inductance in series with the capacitance. This will include the inductance of the leads and the self inductance of the capacitor, as well as any mutual inductance which exists between them. The total inductance is:

$$L = (f_2X_2 - f_1X_1)/2\pi(f_2^2 - f_1^2) \quad (\mu H) \tag{5-6}$$

where $f_2 > f_1$ (f in MHz)

and $$X = -Z_o \tan[(f/f_o)90^o] \quad (\Omega) \tag{5-7}$$

The subscripts for f and X in (5-7) must match. In (5-6), L is in microhenries when f_1 and f_2 are in megahertz. The sign of the reactance derived from (5-7) should reflect the effective reactance of the test component at that frequency. If the device is capacitive, the sign should be negative; if inductive, it should be positive.

Using the information given earlier, let f_2 = 258.9 MHz and f_1 = 36.2 MHz.

$$X_1 = -75.75\tan[(36.2/129.72)90^o] \tag{5-7}$$

$$X_1 = -35.51\ \Omega$$

and

$$X_2 = -75.75\tan[(258.9/129.72)90^o] \tag{5-7}$$

$$X_2 = 0.4953\ \Omega$$

Substituting in (5-6):

$$L = (258.9 \times 0.4953 - 36.2 \times -35.51)/6.283(258.9^2 - 36.2^2) = 0.00342\ \mu H \tag{5-6}$$

Using other combinations of the three frequencies given previously we find that L = 3.57 nH and L = 3.54 nH, the average value being 3.51 nH. The resonant frequency of the device with its leads is approximately 245 MHz.

5.10 RADIAL LEAD SWALLOWER FOR SHUNT MODE MEASUREMENTS, MODEL 34-3A

When shunt mode measurements must be made with radial leaded capacitors, the Model 34-3A Radial Lead Swallower permits the insertion of the leads without distortion, and without including the stray capacitance of the leads.

The Model 34-3A Radial Lead Swallower consists of a pair of hollow square tubes with internal spring contacts and external flanges to accommodate the clamping provisions for shunt mode measurements at the open end of the 34A.

5.10.1 INSTALLATION

The lead swallower and bracket which forms a "J" should be clamped in the slot in the center conductor with the tube parallel and to the left side of the center conductor, as viewed from the open end. The other swallower, which forms an "L", should be fastened under the wall clamp on the left side. The sketch in Figure 5-1 shows the general arrangement.

The Model 34-3A is designed for nominal lead spacing of 0.05 inch (1.270 mm) to 0.25 inch (6.350 mm). Wider spacing may be accommodated with judicious arrangement of the outer (wall) tube, or even transferring the center tube to the right side of the center conductor. If spacing in the order of 0.03 inch is needed, or if greater rigidity is required for low values of test capacitance, a thin piece of teflon can be placed between the two tubes for isolation and they can be held together with a short length of shrinkable teflon tubing. This has the disadvantage of increasing both the capacitance and loss of the fixture.

5.10.2 FIXTURE CAPACITANCE AND Q-FACTOR

The capacitance between elements of the Model 34-3A Lead Swallower is generally controlled by the spacing between the tubes, minimum spacing consistent with lead requirements being desirable. The capacitance can be reduced further by shortening the tubes, provided the radial leads of the test specimen do not extend beyond the ends of the tubes. Owing to the length of the spring contacts, the minimum length of the tubes is 0.5 inch.

The Q-factor and capacitance of the Model 34-3A Radial Lead Swallower must be measured with the two elements securely in position. For accurate results, the Model 34A Resonant Coaxial-Line should be set up according to Paragraph 5.2, using the plunger and ferrule clamp to provide a low resistance-short-circuit.

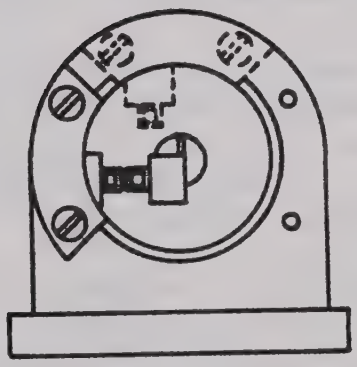

Figure 5-1

The short-circuited condition should establish a Q-factor for the line that is very nearly equal to that specified. The initial values of f_o and Q_o should be noted, and then the Model 34-3A can be installed. The fixture can be treated as a capacitor and measurements made to determine the capacitance and Q-factor. Unless special mounting arrangements have spoiled the loss, the Q-factor will be greater than 5000 and will not usually influence the measurement of the test capacitor. The extent of the influence can be found with the equations which follow.

The capacitance of the 34-3A Radial Lead Swallower must be known in order to make corrections for the Q-factor and capacitance of the test specimen, especially for low capacitance specimens.

The Q-factor of the fixture can be calculated with the aid of (4-1), (4-2), (5-1), (5-2), and (5-3). The capacitance may be found with (3-1).

With the Model 34-3A in place, let the measured capacitance be C_f* and the measured Q-factor equal Q_f. The measured parameters with the test capacitor installed in the lead swallower can be designated C_m and Q_m. Then,

$$\text{test specimen capacitance} = C_x = C_m - C_f \tag{5-8}$$

and,

$$\text{test specimen Q-factor} = Q_c = \frac{Q_f}{\left(\frac{C_f}{C_x}+1\right)\frac{Q_f}{Q_m}-\frac{C_f}{C_x}} \tag{5-9}$$

If $Q_f >> Q_m$,

$$Q_c = Q_m[(C_f/C_x) + 1] \tag{5-10}$$

5.10.3 CORRECTIONS

The following example will explain the use of the above equations.

The half-voltage frequencies for a short-circuited resonant line are f_a = 129.8124 MHz and f_b = 129.6227 MHz. From this, Q_o = 1184.4 at f_o = 129.718 MHz. After installing the 34-3A Lead Swallower, the half-voltage frequencies measured f_a = 123.9805 MHz and f_b = 123.7936 MHz. From previous measurements of the line, x = 0.441. From (3-8), Q_f = 9534; and from (3-1), C_f = 1.20 pF.

With a 22 pF capacitor inserted into the fixture, the half-voltage frequencies were f_a = 73.2607 MHz and f_b = 72.9352 MHz. The apparent parameters of this capacitor calculate to be:

*After the fixture is installed, allow a few minutes for thermal stabilization before making measurements. Dimensional changes owing to thermal differences make Δf measurements difficult, if not impossible.

$$C = 23.51 \text{ pF} \quad (3\text{-}1)$$

$$Q = 480 \quad (5\text{-}3)$$

The actual capacitance equals:

$$C = 23.51 - 1.20 = 22.31 \text{ pF} \quad (5\text{-}8)$$

and, if (5-9) is used, the corrected Q-factor equals:

$$Q_c = \frac{9534}{\left(\frac{1.2}{22.31} + 1\right)\frac{9534}{480} - \frac{1.2}{22.31}} = 456.7 \quad (5\text{-}9)$$

Because $Q_f >> Q_m$, we can use (5-10) which yields:

$$Q_c = \frac{480}{(1.2/22.31) + 1} = 455.5 \quad (5\text{-}10)$$

which is sensibly equal to the results of (5-9).

Equation (5-10) can also be used for 3/4 wavelength mode measurements of most capacitors owing to the normal decline of Q-factors of capacitors at higher frequencies, whereas the value of Q_f will usually remain several thousand or more in this mode.

5.10.4 INPUT COUPLING

Many types of radial leaded capacitors have relatively low Q-factors, especially those with large values of capacitance. The response of the rf millivoltmeter to a low system Q-factor will be attendantly low, and to avoid using the lowest range of the millivoltmeter (1 mV, f.s.), the input coupling should be increased to permit operation of the millivoltmeter on the 3 mV range.

Rotating the input coupling loop, which consists of a 50 ohm metal film resistor, so that it coincides with the plane of the center conductor will sometimes be sufficient. If it is not, the spare TNC connector supplied with the Model 34A can be equipped with a larger loop which may or may not include a 50 ohm resistor. In some cases the coupling loop may need two turns, particularly for low Q specimens at low frequencies.

The coupling is normally low to minimize loss introduced into the line from the signal source. The normal adjustment of coupling, however, is lower than needed, even for medium to high Q

specimens. Because the introduced loss is a function of f^2, and its influence is somewhat proportional to the Q-factor of the test capacitor, a two-turn loop for low Q specimens at low frequencies will not substantially impair the accuracy of the measurement. Whenever possible a check should be made using the 1 mV range of the millivoltmeter and the minimum coupling required to achieve a full-scale response at the resonant test frequency. Essentially the same result should obtain using the 3 mV range and greater input coupling.

The purpose of the 50 ohm resistor in the coupling loop is to provide a reasonable termination for the cable between the signal source and the Model 34A, and to keep the swr in bounds and avoid a possible resonant condition under which insufficient energy would be transmitted to the 34A.

5.10.5 FIXTURE INDUCTANCE

The total series inductance of radial leaded capacitors, which includes the self inductance of the capacitor, the lead inductance to the point of contact in the fixture, and the fixture inductance may be found by the technique described in Paragraphs 5.8 and 5.9. To find the inductance of just the capacitor and its leads, the fixture inductance must be known and deducted from the total inductance. Before measuring the total inductance, the capacitor may be partially withdrawn from the fixture to approximate the actual circuit lead length, if that is of interest.

A good approximation of the fixture inductance can be made by adjusting the position of the tubes so that they make contact at the insertion end. Under this condition, find one of the resonant frequencies and calculate the reactance with (5-7). The fixture inductance is:

$$L_f = X_f/\omega \tag{5-11}$$

For example, with the Model 34-3A installed, contact was made by moving the outer (grounded) tube a few mils. The measured resonant frequency was 258.16 MHz.

$$X_f = -75.75 \tan[(258.16/129.72)90^\circ] \tag{5-7}$$
$$X_f = 1.174 \text{ ohms}$$

and,

$$L_f = 1.174/(6.2832 \times 258.16) = 0.000724 \ \mu H \tag{5-11}$$

Deduct this from the total measured inductance of the capacitor, which was determined from (5-6).

If the spacing of the tubes of the Model 34-3A Lead Swallower has been set for a lead spacing of greater than, say, 0.20 inch, so that moving the outer tube to contact the center tube will materially alter the original configuration, a shorting element can be inserted between the tubes. The calculated inductance of the shorting element should be subtracted from the measured fixture inductance (see (4-8) in Paragraph 4-3). The inductance of the shorting strap may also be measured in the series mode, as described in Section VII.

5.11 ESR FIXTURE FOR LARGE CAPACITANCE, MODEL 34-3B

The effective series resistance of by-pass, blocking, and other high capacitance devices can be measured at high frequencies with the Model 34A. These capacitors are normally self resonant at relatively low frequencies, and they become inductive at higher frequencies.

With the aid of a Model 34-3B fixture, which has a built-in series capacitor of about 7 pF and provides for the insertion of radial leaded or DIP components, the esr of these devices can be measured at approximately 100 MHz, 320 MHz, and if the esr is not too high, at 550 MHz, or higher.

A plot of the fixture resistance is supplied with each Model 34-3B, and we suggest that this chart be attached with paper cement to this page in the space provided (Figure 5-2).

Figure 5-2

The resistance of each Model 34-3B need not, in general, be known to any greater accuracy than given. Measurements of the esr of large capacitance devices are usually made for the purpose of comparison, or selecting defective capacitors, and the repeatability of the measurement, rather than the absolute accuracy is the important factor. If greater accuracy is required, the 34-3B may be measured for esr using the technique described in Section VII.

5.11.1 MEASURING ESR OF LARGE CAPACITANCE

The installation of the Model 34-3B is the same as for the 34-3A, described in Section 5.10.1, and the possible need of increased input coupling, as covered in Section 5.10.4, is applicable.

The spacing of the two square tubes which accommodate the radial leads should be adjusted for the capacitors to be measured. If the components have axial leads they must be altered to permit insertion into the tubes.

With the test specimen in place, which puts it in series with the built-in work capacitor (7 pF) of the fixture, a shunt mode measurement of the combination is made. The total esr is calculated from (5-2) and the fixture resistance of the Model 34-3B (Figure 5-2) for the particular measurement frequency is then subtracted from the total esr, leaving the esr of the test specimen, or

esr of test specimen = total esr (5-2) - fixture resistance (Figure 5-2)

A Model 34-3B Adapter is characterized as follows:

Frequency	ESR
100.15 MHz	80.8 mΩ
319.29 MHz	144.0 mΩ

A 0.047 µF by-pass capacitor connected in the 34-3B Adapter has a measured esr of 225 mΩ at 100 MHz, and 350 mΩ at 315 MHz. The frequency of interest is 150 MHz. Plotting the loss of the Adapter, as well as the test capacitor, yields:

Frequency	ESR of Adapter	ESR of Capacitor
150 MHz	100 mΩ	292 mΩ

The effective series resistance of the capacitor is approximately 292 - 100 = 192 milliohms at 150 MHz.

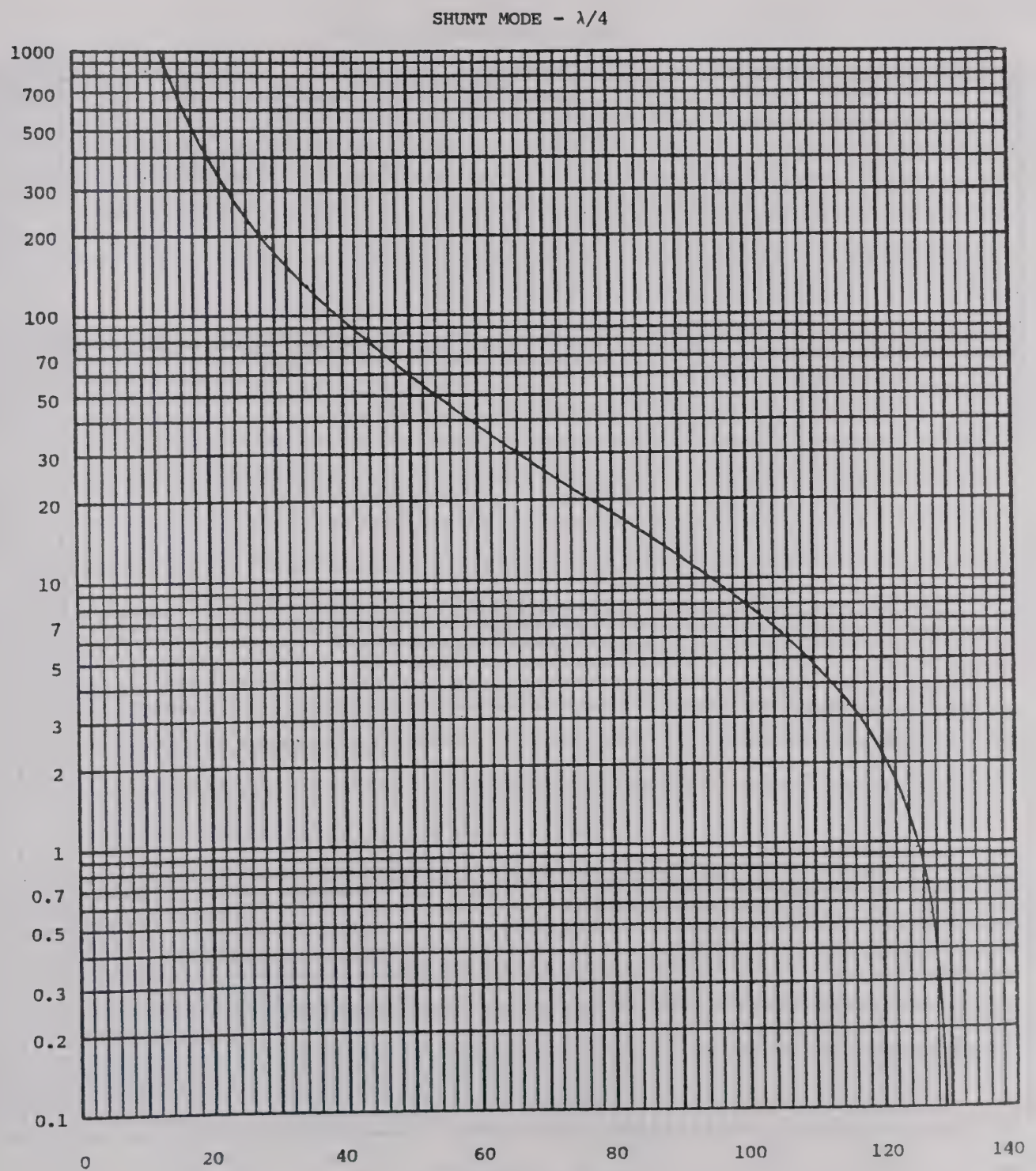

Figure 5-3

34B
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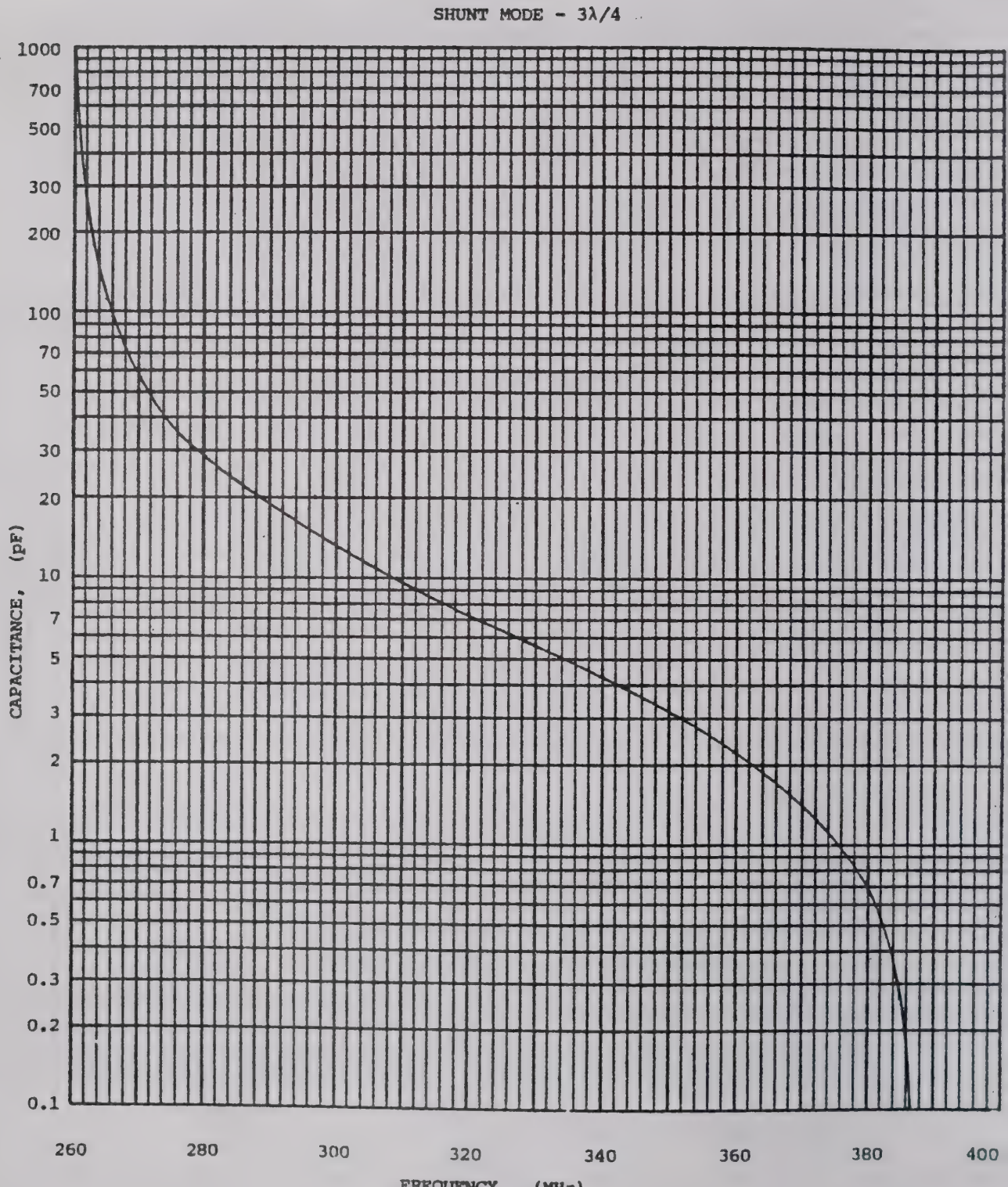

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Figure 5-4

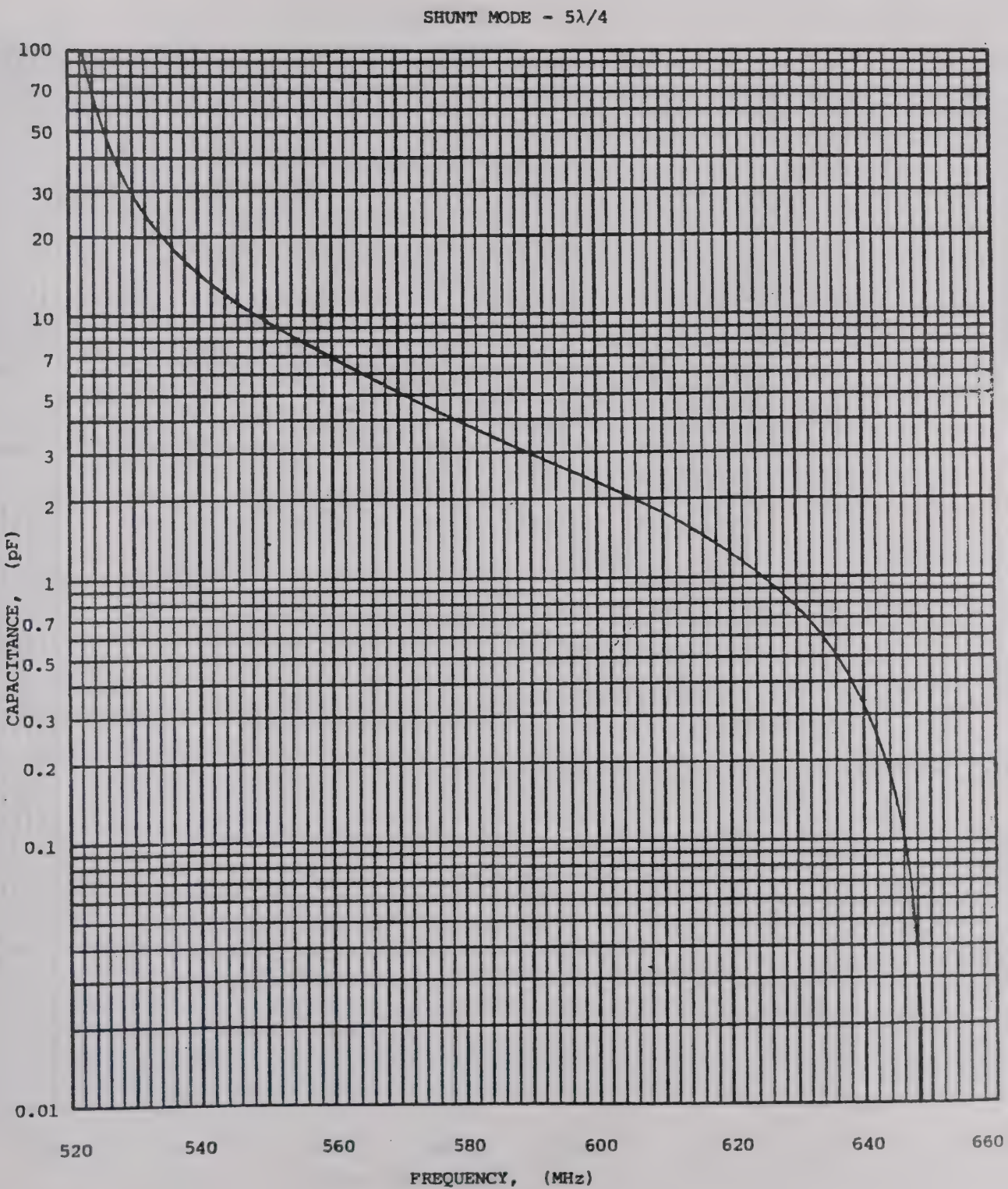
SHUNT MODE - 5λ/4
100
70
50
30
20
10
7
5
3
2
1
0.7
0.5
0.3
0.2
0.1
0.01
CAPACITANCE, (pF)
520
540
560
580
600
620
640
660
FREQUENCY, (MHz)

Figure 5-5

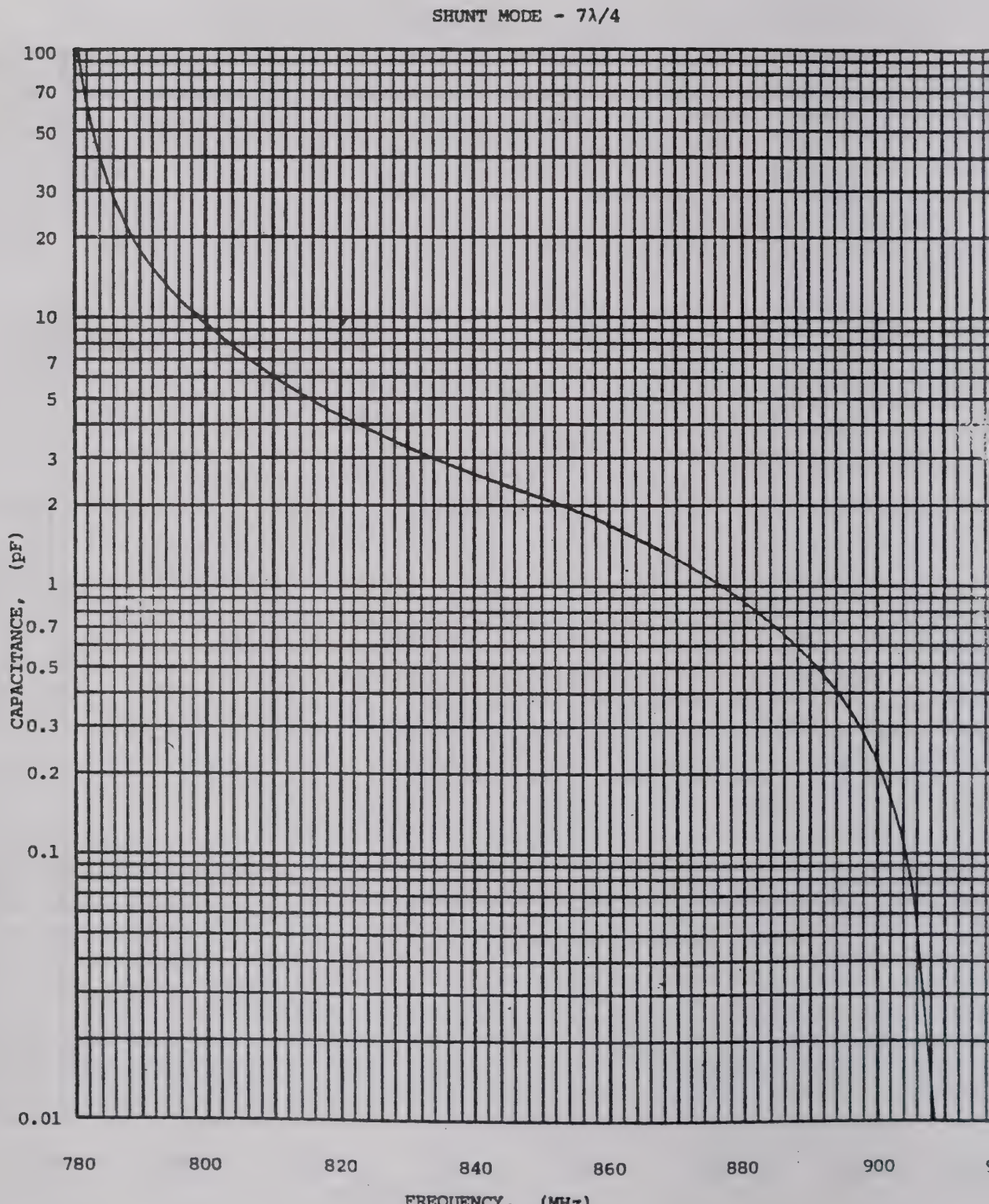

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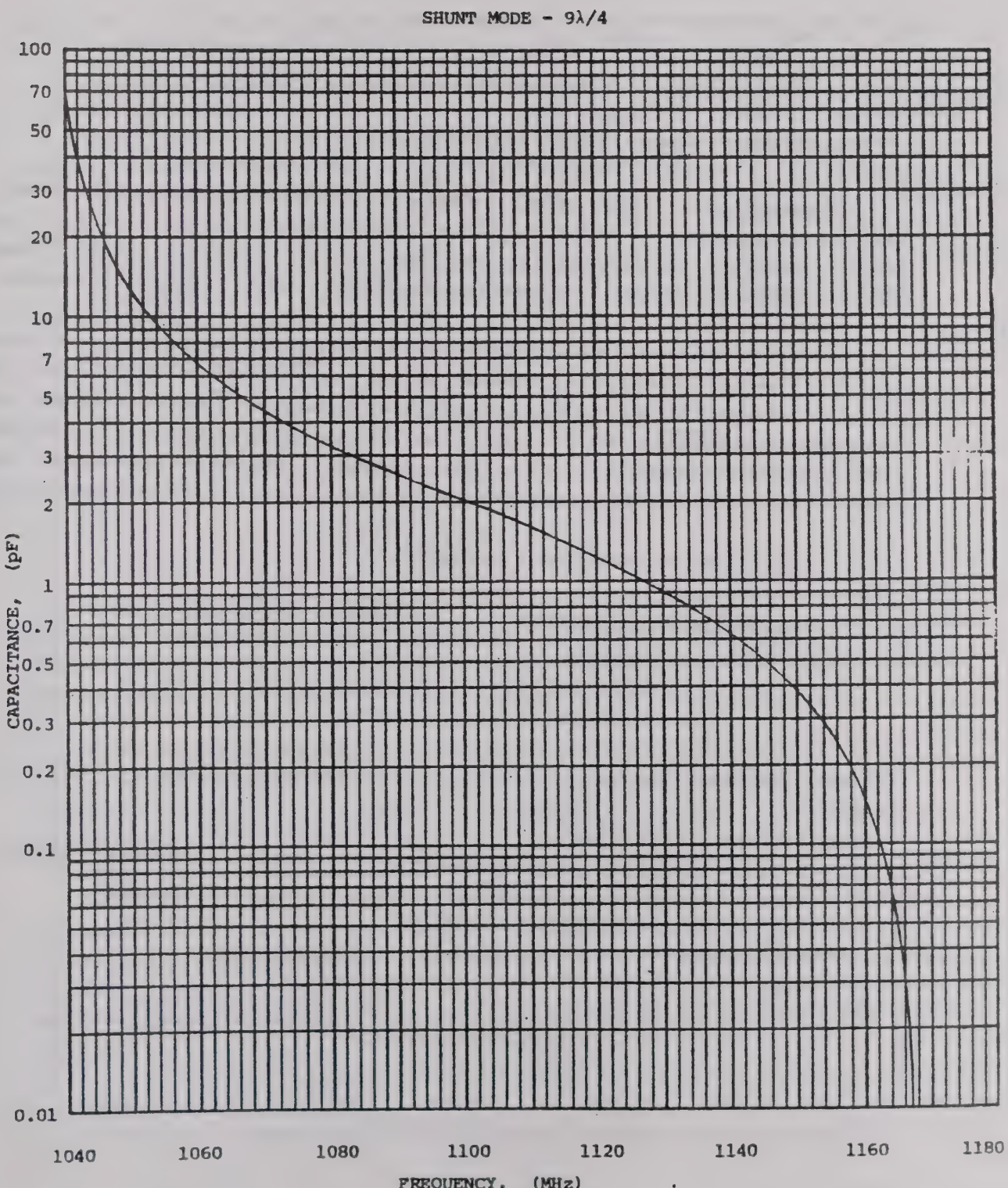
Figure 5-6



34B
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Figure 5-7

SECTION VI

MEASURING 34A PARAMETERS

6.1 SHORT-CIRCUITED Q-FACTOR, Q_o, AND RESONANT FREQUENCY, f_o

To measure the loss of shunt connected components, it is necessary to know the Q-factor of the transmission line in the short-circuited mode at the measurement frequency. It can be extrapolated accurately from the measured Q-factor of the line at the fundamental resonant frequency ($\lambda/4$, or approximately 130 MHz), and these parameters are designated Q_o and f_o, respectively.

The slope of the short-circuited Q-factors vs frequency (for a log-log plot) at odd quarter-wavelength resonant frequencies is also needed for this extrapolation. The slope is denoted as x. We recommend that it be derived from the measured Q-factors at $\lambda/4$ and $3\lambda/4$. Because conventional capacitors exhibit higher Q-factors at lower frequencies, it is important that the Model 34A be characterized accurately at the two lowest frequencies. Averaging the Q-slope for three or more resonant frequencies may compromise the line Q-factors in the lower frequency spectrum.

The short-circuit parameters for a line measure:

Resonant Frequencies	Q-Factors
130.00 MHz	1200
390.00 MHz	1967
650.00 MHz	2476

These parameters were measured with the 34-1A High Impedance RF Probe, and the 34-2A Cut-Off Attenuator.

The factor x, which is the slope of the Q-factor vs. frequency, may be calculated from:

$$x = \log(Q_2/Q_1)/\log(f_2/f_1) \qquad (6\text{-}1)$$

In this case:

$$x = \log(1967/1200)/\log(390/130)$$
$$x = 0.4942/1.0986 = 0.450$$

The plot of Q vs. frequency is shown in Figure 6-1.

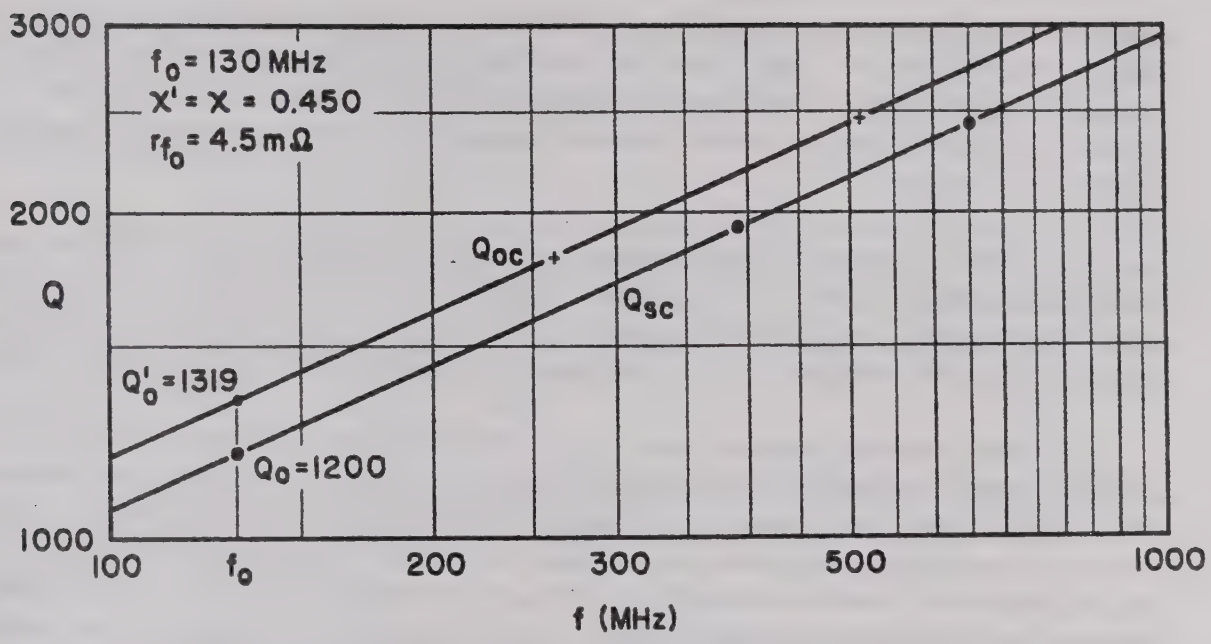


Figure 6-1

The precautions necessary to insure a proper short circuit at the closed end of the transmission line are described in Section V, Paragraph 5.2. When the plunger is correctly mated with the center conductor of the line to produce a good short circuit, the fundamental resonant frequency, f_o, and the short-circuited Q-factor of the line, Q_o, may be measured.

The quarter-wavelength resonant frequency of the Model 34A is approximately 130 MHz. It is equal to the arithmetic mean of the two half-voltage frequencies on either side of resonance. The Q-factor of the Model 34A at this frequency is a measure of the difference of these two frequencies, Δf. The same procedure can be used at any of the odd quarter-wavelength frequencies.

We recommend that the Model 34-2A Cut-Off Attenuator be installed for all line parameter measurements, and that the Model 34-1A High Impedance RF Probe be used for frequencies above 500 MHz, and for lower frequencies, if it is available. If the probe is not available, and all measurements are to be confined to frequencies under 500 or 600 MHz, we suggest using the line parameters given on the calibration card mounted on the inside cover of the walnut case for the Model 34A.

The Q-factor of the Model 34A is determined by measuring two frequencies, one on each side of a resonant peak response at a predetermined ratio of resonant to off-resonant voltage. We

recommend using frequencies above and below resonance which yield one-half the voltage that obtains at the resonant peak. This 2-to-1 ratio provides the best accuracy, relative to the millivoltmeter readings. Smaller deviations of frequency give smaller changes of voltage, which promote scale-reading errors. Greater deviations produce down-scale readings with attendantly greater instrument error.

Set the output frequency of the generator to a resonant frequency of the line, as evidenced by a maximum response of the rf millivoltmeter. Adjust the coarse and vernier controls for both frequency and output level, alternately, until a peak reading of exactly 3.0 mV is indicated on the meter. The final settings will be found through mutual adjustments of the vernier controls.

The signal generator frequency should then be adjusted above resonance until the rf millivoltmeter reading decreases to one-half of its former value, i.e., 1.5 mV. When the millivoltmeter reads 1.5 mV, or very nearly so, the generator frequency can be locked by depressing the LOCK pushbutton. The upper VERNIER control, which is integral with the phase-lock circuitry, can be adjusted for a reading of exactly 1.5 mV and the indicated output frequency will remain quiescent, as will the millivoltmeter reading. As more experience is acquired, it may be possible at the lower frequencies to make measurements without benefit of the phase lock feature. At higher frequencies, however, the added stability of the locked VFO will generally be helpful.

Let the frequency above resonance be f_a. It should be recorded, or entered into a programmed calculator. The Model 102D Signal Generator should be set for maximum resolution of the displayed frequency, which temporarily drops the most significant digit, but displays the output frequency in MHz to four decimal places, or a resolution of 100 Hz. All seven digits should be recorded.

The VFO should then be unlocked and the frequency lowered through and below resonance to a point where the rf millivoltmeter again reads 1.5 mV. The phase-lock circuitry may be re-engaged and the frequency that gives a meter reading of exactly 1.5 mV should be recorded. This frequency is f_b.

If the resonant frequency of the line is denoted as f_o, its value is calculated by taking the arithmetic mean of f_a and f_b, or,

$$f_o = (f_a + f_b)/2 \qquad (6\text{-}2)$$

The Q-factor of the line is found from:

$$Q_o = \sqrt{3} f_o/\Delta f \qquad (6\text{-}3)$$

where,

$$\Delta f = f_a - f_b \qquad (6\text{-}4)$$

and f_o is given by (6-2).

The factor of $\sqrt{3}$ is derived from $\sqrt{m^2 - 1}$, where m is the ratio of resonant to off-resonant voltage. When m = 2 the factor is $\sqrt{3}$.

6.2 OPEN-CIRCUITED Q-FACTOR, Q'_o

To measure the loss of series connected components, it is necessary to know the Q-factor of the system with the test component installed in series with the line, as well as the Q-factor of the transmission line, Q_l, at the measurement frequency, f_l. Q_l must be extrapolated from measured values of the open-circuit Q-factors of the line at the natural frequencies of resonance, $\lambda/2$, λ, $3\lambda/2$, etc., and x', which is the slope of Q_{oc} vs. frequency. This is described in Figure 6-1.

The Model 34A should be open circuited by removing the plunger and threaded ferrule clamp from the bushing in the end plate. The lowest resonant frequency occurs at approximately 258 MHz, the second at about 516 MHz.

It is recommended that the slope, x', be determined from the Q-factors measured at these two frequencies because the measurement of higher Q-factors at higher frequencies is subject to greater error, and averaging the slope may compromise the lower frequency Q-factors. It is in this region that the majority of test components will exhibit minimum loss, hence the need for maximum accuracy. It is also essential that the Model 34-2A Cut-Off Attenuator be installed for these measurements, and if the Model 34-1A High Impedance RF Probe is not available, we recommend that the published values of Q'_o and x' be used in lieu of less accurate measurements made without the benefit of this probe. This is not to suggest that satisfactory measurements of test specimens cannot be made without this probe. It is only when measuring Q-factors above, say, 1500, that the Model 34-1A will permit more accurate measurements, even at frequencies below 500 or 600 MHz.

Assume that the open-circuit parameters of a line measure:

Resonant Frequencies	Q-Factors
258.00	1796
516.00	2453

The slope may be calculated from (6-1).

$$x' = \log(2453/1796)/\log(516/258)$$
$$x' = 0.450$$

These values are shown in Figure 6-1. It is necessary now to extrapolate the value of Q'_o for the frequency, f_o. This is simply,

$$Q'_o = (f_o/f_{oc})^{x'} Q_{oc} \qquad (6\text{-}5)$$

Substituting from the example:

$$Q_o' = (130/258)^{0.45}(1796) = 1319 \qquad (6\text{-}5)$$

For a further discussion of Q_o', refer to Paragraph 4.2.2.

6.3 FIXTURE RESISTANCE, r_f

Extrapolating the open-circuited Q-factor, Q_o', to find the Q-factor of the line at the measurement frequency, Q_1 and f_1, respectively, ignores the series resistance of the plunger and ferrule clamp (test fixture). This is because this fixture is divorced from the line for the measurement of the open-circuit Q-factors. It becomes necessary, therefore, to deduct the fixture resistance from the calculated esr. Obviously, the value to deduct is the fixture resistance at the measurement frequency. The fixture resistance given on the calibration card, r_{f_0}, is for the frequency, f_o. It should actually be for f_o', but because this frequency is a function of the configuration of the test specimen, it can only be specified for f_o. These frequencies are sufficiently close as to preclude the necessity for a correction. The condition is closely related to the difference between Q_o' at f_o and at f_o', a subject that is covered in Paragraph 4.2.2.

The fixture resistance at any frequency, f_1, is related to r_{f_0} as follows:

$$r_f = r_{f_0}(f_1/f_o)^{(1 - x')} \qquad (6\text{-}6)$$

This relationship holds only if the two slopes, x and x', are sensibly equal. Theoretically, the slopes should be equal, and practically, they are sufficiently close to permit the use of (6-6) to determine the fixture resistance at the measurement frequency, f_1.

The fixture resistance at f_o is a function of the difference between Q_o and Q_o'. If the fixture resistance were zero, these terms would be equal. It can be shown that,

$$r_{f_0} = \pi Z_0[(1/Q_o) - (1/Q_o')]/4 \qquad (6\text{-}7)$$

For the example previously given:

$$r_{f_0} = 3.1416 \times 75.75[(1/1200) - (1/1319)]/4 \qquad (6\text{-}7)$$

$$r_{f_0} = 0.0045\ \Omega, \text{ or } 4.5\ \text{m}\Omega$$

If the measurement frequency is, say, 240 MHz, the series resistance of the fixture is, at that frequency, $0.0045(240/130)^{(1 - 0.45)} = 0.0059\ \Omega$.

6.4 INPUT COUPLING

When measuring test specimens with relatively large values of effective series resistance, hence low Q-factors, it may be necessary to increase the degree of coupling between the signal generator and the resonant line.

If rotating the coupling loop, which is formed by the 50-ohm terminating resistor, is sufficient to yield an rf millivoltmeter reading of 3 mV, with full output from the generator, no special precautions need be taken. This degree of coupling should not be great enough to seriously affect the accuracy of measurement, considering, of course, that the specimen Q-factors are low.

Should the Q-factors be immoderately low, so as to require a higher degree of coupling, a 1- or 2-turn coupling loop may be formed with the spare TNC connector provided, and substituted for the regular loop. This amended loop may, if necessary, be terminated with a 50-ohm resistor to improve the s.w.r.

A matter of much importance is the possiblity of reflected loss into the line at measurement frequencies. This can be so great with a 2-turn loop at higher frequencies as to invalidate a measurement. Fortunately, the test for this condition is simple. The Q-factor of the line should, if possible, be measured in the neighborhood of the test frequency, or above and below the test frequency. The line may be short, or open-circuited, depending upon what is needed to achieve line resonance in the neighborhood of the test frequency.

If the line is unduly influenced by the high degree of coupling, the Q-factor will depart substantially from the value extrapolated from Q_o or Q'_o, and the slope, x or x'. The extent to which a reduction can be tolerated depends largely upon the loss of the test specimen. For example, if a 20 pF capacitor has an esr of 0.98 ohm at 660 MHz ($Q \approx 12$), a reduction of 20% for the Q-factor of the line will only influence the measured loss by a few percent. For specimens with higher Q-factors, the influence will be greater.

BASIC CM

Q_o - 12.9%
X_1 = .464
R_o = .004
f_o = 130

FIXED LINE PARAM

SECTION VII

CALCULATOR PROGRAMS

7.1 HP 67/97 AND TI 59 PROGRAMS

The equations presented in Sections IV and V make it evident that a programmable calculator is essential if more than a few measurements are to be made. A number of programmable calculators are available that can perform this function. Listings of the program steps for series and shunt measurements for two popular models are given in this section. Many variations are possible; these listings should serve as a guide.

These programs provide for print-out of the line parameters, the two entered variables (f_a and f_b), and the parameters of the test specimen. When using the Model HP 67, or the Model TI 59 without the PC-100C printer, delete the print commands for the entered parameters and change print commands for the test specimen parameters to run/stop (R/S) commands. The calculators will then stop and display each of the desired parameters until the R/S key is depressed, which permits the user to record the data.

HP 97: The programs given require the use of both tracks on the magnetic data card for the HP 97. After entering and recording the program, the program is initiated by depressing the E key. This directs the calculator to accept four line parameter entries for the series mode calculation, and three for the shunt mode. These entries are made with the R/S key, and they are printed and stored in registers 1 through 4 (1 through 3 for the shunt mode). The variables, f_a and f_b are entered with the A and B keys, respectively, and the programs run after the entry in B.

TI 59: The programs given require the use of two banks, 1 and 2. These banks must be identified when recording and loading the programs. The program is initiated, as described above for the HP 97, by depressing the E key, etc.

EXAMPLE INPUT
Q_o' = 1309
f_o' = .0041
x' = .444
f_o = 127.7 MHz
f_o' = 124.5 MHz
f_{a1} = 143.3567
f_{a2} = 143.0115

The order of operations for both the HP and TI calculators are as follows:

1. Load program into calculator.
2. Depress the E key.
3. Enter f_o' and depress R/S key. (Enter f_o for shunt measurements)
4. Enter Q_o' and depress R/S key. (Enter Q_o for shunt measurements)

OUTPUT OF EXAMPLE
143.18 = f1
.0445 = ESR
8259 = CAP IN P
285 = Q

- ENTER FREQ NUMBERS ONLY - DO NOT INCLUDE THE MHZ
- ANSWER OF CAP WILL BE IN pf

5. Enter x' and depress R/S key. (Enter x for shunt measurements)
6. Enter r_{f_0} and depress R/S key (series mode, only).
7. Enter f_a and depress A key.
8. Enter f_b and depress B key.
9. Depressing the D key will recall and print the line parameters.
10. Depressing the (f)d key will recall and print Q_m, Q_l', and $1/\omega C$. For the shunt mode, the second term printed is Q_l

7.2 H-P SERIES PROGRAM

001	*LBLE	21 15	034	STO5	35 05	067	0	00
002	DSP2	-63 02	035	RCLA	36 11	068	×	-35
003	R/S	51	036	RCLB	36 12	069	TAN	43
004	PRTX	-14	037	-	-45	070	1/X	52
005	STO1	35 01	038	÷	-24	071	2	02
006	R/S	51	039	3	03	072	÷	-24
007	DSP0	-63 00	040	$\sqrt{X}$	54	073	-	-45
008	PRTX	-14	041	×	-35	074	RCL6	36 06
009	STO2	35 02	042	STO6	35 06	075	1/X	52
010	R/S	51	043	RCL5	36 05	076	RCL7	36 07
011	DSP3	-63 03	044	RCL1	36 01	077	1/X	52
012	PRTX	-14	045	÷	-24	078	-	-45
013	STO3	35 03	046	STOI	35 46	079	×	-35
014	R/S	51	047	RCL3	36 03	080	7	07
015	DSP4	-63 04	048	Y^X	31	081	5	05
016	PRTX	-14	049	RCL2	36 02	082	.	-62
017	STO4	35 04	050	×	-35	083	7	07
018	SPC	16-11	051	STO7	35 07	084	5	05
019	RTN	24	052	RCLI	36 46	085	×	-35
020	*LBLA	21 11	053	9	09	086	RCLI	36 46
021	DSP4	-63 04	054	0	00	087	1	01
022	PRTX	-14	055	×	-35	088	RCL3	36 03
023	STOA	35 11	056	SIN	41	089	-	-45
024	RTN	24	057	1/X	52	090	Y^X	31
025	*LBLB	21 12	058	X^2	53	091	RCL4	36 04
026	PRTX	-14	059	RCLI	36 46	092	×	-35
027	STOB	35 12	060	×	-35	093	-	-45
028	SPC	16-11	061	Pi	16-24	094	DSP4	-63 04
029	+	-55	062	×	-35	095	PRTX	-14
030	2	02	063	4	04	096	STO8	35 08
031	÷	-24	064	÷	-24	097	RCLI	36 46
032	DSP2	-63 02	065	RCLI	36 46	098	9	09
033	PRTX	-14	066	9	09	099	0	00

(continued)

7.2 H-P 97 SERIES PROGRAM (CONTINUED)

100	×	-35	134	SPC	16-11	168	PRTX	-14
101	TAN	43	135	SPC	16-11	169	RCL3	36 03
102	1/X	52	136	SPC	16-11	170	DSP3	-63 03
103	CHS	-22	137	SPC	16-11	171	PRTX	-14
104	7	07	138	SPC	16-11	172	RCL4	36 04
105	5	05	139	DSP4	-63 04	173	DSP4	-63 04
106	.	-62	140	RTN	24	174	PRTX	-14
107	7	07	141	*LBLC	21 13	175	SPC	16-11
108	5	05	142	RCL9	36 09	176	SPC	16-11
109	×	-35	143	CHS	-22	177	SPC	16-11
110	STO9	35 09	144	Pi	16-24	178	SPC	16-11
111	Pi	16-24	145	÷	-24	179	DSP4	-63 04
112	×	-35	146	2	02	180	RTN	24
113	2	02	147	÷	-24	181	*LBLd	21 16 14
114	×	-35	148	RCL5	36 05	182	RCL6	36 06
115	EEX	-23	149	÷	-24	183	DSP1	-63 01
116	6	06	150	EEX	-23	184	PRTX	-14
117	×	-35	151	3	03	185	RCL7	36 07
118	RCL5	36 05	152	×	-35	186	PRTX	-14
119	×	-35	153	DSP3	-63 03	187	RCL9	36 09
120	1/X	52	154	PRTX	-14	188	DSP2	-63 02
121	EEX	-23	155	SPC	16-11	189	PRTX	-14
122	1	01	156	SPC	16-11	190	SPC	16-11
123	2	02	157	SPC	16-11	191	SPC	16-11
124	×	-35	158	SPC	16-11	192	SPC	16-11
125	DSP2	-63 02	159	SPC	16-11	193	SPC	16-11
126	PRTX	-14	160	DSP4	-63 04	194	DSP4	-63 04
127	X<0?	16-45	161	RTN	24	195	RTN	24
128	GTOC	22 13	162	*LBLD	21 14	196	R/S	51
129	RCL9	36 09	163	RCL1	36 01			
130	RCL8	36 08	164	DSP2	-63 02			
131	÷	-24	165	PRTX	-14			
132	DSP1	-63 01	166	RCL2	36 02			
133	PRTX	-14	167	DSP0	-63 00			

7.3 H-P 97 SHUNT PROGRAM

001	*LBLE	21 15	040	RCL1	36 01	079	5	05
002	DSP2	-63 02	041	÷	-24	080	×	-35
003	R/S	51	042	STOI	35 46	081	DSP4	-63 04
004	PRTX	-14	043	RCL3	36 03	082	PRTX	-14
005	STO1	35 01	044	Y^x	31	083	STO8	35 08
006	R/S	51	045	RCL2	36 02	084	RCLI	36 46
007	DSP0	-63 00	046	×	-35	085	9	09
008	PRTX	-14	047	STO7	35 07	086	0	00
009	STO2	35 02	048	RCLI	36 46	087	×	-35
010	R/S	51	049	9	09	088	TAN	43
011	DSP3	-63 03	050	0	00	089	7	07
012	PRTX	-14	051	×	-35	090	5	05
013	STO3	35 03	052	COS	42	091	.	-62
014	SPC	16-11	053	1/X	52	092	7	07
015	RTN	24	054	X^2	53	093	5	05
016	*LBLA	21 11	055	RCLI	36 46	094	×	-35
017	DSP4	-63 04	056	×	-35	095	STO9	35 09
018	PRTX	-14	057	Pi	16-24	096	Pi	16-24
019	STOA	35 11	058	×	-35	097	×	-35
020	RTN	24	059	4	04	098	2	02
021	*LBLB	21 12	060	÷	-24	099	×	-35
022	PRTX	-14	061	RCLI	36 46	100	EEX	-23
023	STOB	35 12	062	9	09	101	6	06
024	SPC	16-11	063	0	00	102	×	-35
025	+	-55	064	×	-35	103	RCL5	36 05
026	2	02	065	TAN	43	104	×	-35
027	÷	-24	066	2	02	105	1/X	52
028	DSP2	-63 02	067	÷	-24	106	EEX	-23
029	PRTX	-14	068	+	-55	107	1	01
030	STO5	35 05	069	RCL6	36 06	108	2	02
031	RCLA	36 11	070	1/X	52	109	×	-35
032	RCLB	36 12	071	RCL7	36 07	110	DSP2	-63 02
033	-	-45	072	1/X	52	111	PRTX	-14
034	+	-24	073	-	-45	112	X<0?	16-45
035	3	03	074	×	-35	113	GTOC	22 13
036	$\sqrt{X}$	54	075	7	07	114	RCL9	36 09
037	×	-35	076	5	05	115	RCL8	36 08
038	STO6	35 06	077	.	-62	116	÷	-24
039	RCL5	36 05	078	7	07	117	DSP1	-63 01

(continued)

7.3 H-P 97 SHUNT PROGRAM (CONTINUED)

118	PRTX	-14	139	PRTX	-14	160	SPC	16-11
119	SPC	16-11	140	SPC	16-11	161	DSP4	-63 04
120	SPC	16-11	141	SPC	16-11	162	RTN	24
121	SPC	16-11	142	SPC	16-11	163	*LBLd	21 16 14
122	SPC	16-11	143	SPC	16-11	164	RCL6	36 06
123	SPC	16-11	144	SPC	16-11	165	DSP1	-63 01
124	DSP4	-63 04	145	DSP4	-63 04	166	PRTX	-14
125	RTN	24	146	RTN	24	167	RCL7	36 07
126	*LBLC	21 13	147	*LBLD	21 14	168	PRTX	-14
127	RCL9	36 09	148	RCL1	36 01	169	RCL9	36 09
128	CHS	-22	149	DSP2	-63 02	170	DSP2	-63 02
129	Pi	16-24	150	PRTX	-14	171	PRTX	-14
130	÷	-24	151	RCL2	36 02	172	SPC	16-11
131	2	02	152	DSP0	-63 00	173	SPC	16-11
132	÷	-24	153	PRTX	-14	174	SPC	16-11
133	RCL5	36 05	154	RCL3	36 03	175	SPC	16-11
134	÷	-24	155	DSP3	-63 03	176	DSP4	-63 04
135	EEX	-23	156	PRTX	-14	177	RTN	24
136	3	03	157	SPC	16-11	178	R/S	51
137	×	-35	158	SPC	16-11			
138	DSP3	-63 03	159	SPC	16-11			

7.4 T.I. 59 SERIES PROGRAM

000	76	LBL	010	00	00	020	91	R/S
001	15	E	011	99	PRT	021	58	FIX
002	58	FIX	012	42	STO	022	04	04
003	02	02	013	02	02	023	99	PRT
004	91	R/S	014	91	R/S	024	42	STO
005	99	PRT	015	58	FIX	025	04	04
006	42	STO	016	03	03	026	98	ADV
007	01	01	017	99	PRT	027	91	R/S
008	91	R/S	018	42	STO	028	76	LBL
009	58	FIX	019	03	03	029	11	A

(continued)

7.4 T. I. 59 SERIES PROGRAM (CONTINUED)

030	58	FIX	069	03	3	108	55	÷
031	04	04	070	34	$\sqrt{x}$	109	04	4
032	99	PRT	071	95	=	110	95	=
033	42	STO	072	42	STO	111	42	STO
034	11	11	073	06	06	112	13	13
035	91	R/S	074	43	RCL	113	43	RCL
036	76	LBL	075	05	05	114	09	09
037	12	B	076	55	÷	115	30	TAN
038	99	PRT	077	43	RCL	116	35	1/X
039	42	STO	078	01	01	117	55	÷
040	12	12	079	95	=	118	02	2
041	98	ADV	080	42	STO	119	95	=
042	43	RCL	081	07	07	120	75	-
043	11	11	082	45	Y^x	121	43	RCL
044	85	+	083	43	RCL	122	13	13
045	43	RCL	084	03	03	123	95	=
046	12	12	085	95	=	124	94	+/-
047	95	=	086	65	×	125	65	×
048	55	÷	087	43	RCL	126	07	7
049	02	2	088	02	02	127	05	5
059	95	=	089	95	=	128	93	.
051	58	FIX	090	42	STO	129	07	7
052	02	02	091	08	08	130	05	5
053	99	PRT	092	43	RCL	131	95	=
054	98	ADV	093	07	07	132	42	STO
055	42	STO	094	65	×	133	13	13
056	05	05	095	09	9	134	43	RCL
057	43	RCL	096	00	0	135	06	06
058	11	11	097	95	=	136	35	1/X
059	75	-	098	42	STO	137	75	-
060	43	RCL	099	09	09	138	53	(
061	12	12	100	38	SIN	139	43	RCL
062	95	=	101	35	1/X	140	08	08
063	35	1/X	102	33	X^2	141	35	1/X
064	65	×	103	65	×	142	54	)
065	43	RCL	104	43	RCL	143	95	=
066	05	05	105	07	07	144	65	×
067	95	=	106	65	×	145	43	RCL
068	65	×	107	89	π	146	13	13

(continued)

7.4 T.I. 59 SERIES PROGRAM (CONTINUED)

147	95	=	187	65	×	227	55	÷
148	42	STO	188	43	RCL	228	02	2
149	13	13	189	05	05	229	55	÷
150	43	RCL	190	65	×	230	43	RCL
151	07	07	191	02	2	231	05	05
152	45	Y^x	192	65	×	232	65	×
153	53	(	193	89	π	233	01	1
154	01	1	194	95	=	234	00	0
155	75	-	195	35	1/X	235	00	0
156	43	RCL	196	65	×	236	00	0
157	03	03	197	01	1	237	95	=
158	54	)	198	52	EE	238	58	FIX
159	95	=	199	06	6	239	03	03
160	65	×	200	22	INV	240	99	PRT
161	43	RCL	201	52	EE	241	98	ADV
162	04	04	202	95	=	242	91	R/S
163	75	-	203	58	FIX	243	58	FIX
164	43	RCL	204	02	02	244	04	04
165	13	13	205	99	PRT	245	76	LBL
166	95	=	206	22	INV	246	14	D
167	94	+/-	207	77	GE	247	43	RCL
168	42	STO	208	13	C	248	01	01
169	14	14	209	43	RCL	249	58	FIX
170	58	FIX	210	13	13	250	02	02
171	04	04	211	55	÷	251	99	PRT
172	99	PRT	212	43	RCL	252	43	RCL
173	43	RCL	213	14	14	253	02	02
174	09	09	214	95	=	254	58	FIX
175	30	TAN	215	58	FIX	255	00	00
176	35	1/X	216	01	01	256	99	PRT
177	65	×	217	99	PRT	257	43	RCL
178	07	7	218	98	ADV	258	03	03
179	05	5	219	91	R/S	259	58	FIX
180	93	.	220	76	LBL	160	03	03
181	07	7	221	13	C	261	99	PRT
182	05	5	222	43	RCL	262	43	RCL
183	95	=	223	13	13	263	04	04
184	94	+/-	224	94	+/-	264	58	FIX
185	42	STO	225	55	÷	265	04	04
186	13	13	226	89	π	266	99	PRT

(continued)

7.4 T.I. 59 SERIES PROGRAM (CONTINUED)

267	98	ADV	275	99	PRT	283	99	PRT
268	91	R/S	276	43	RCL	284	98	ADV
269	76	LBL	277	07	07	285	98	ADV
270	19	D'	278	99	PRT	286	58	FIX
271	43	RCL	279	43	RCL	287	04	04
272	06	06	280	09	09	288	91	R/S
273	58	FIX	281	58	FIX	289	00	0
274	01	01	282	02	02			

7.5 TI 59 SHUNT PROGRAM

000	76	LBL	024	58	FIX	048	42	STO
001	15	E	025	04	04	049	05	05
002	58	FIX	026	99	PRT	050	98	ADV
003	02	02	027	42	STO	051	43	RCL
004	91	R/S	028	11	11	052	11	11
005	99	PRT	029	91	R/S	053	75	-
006	42	STO	030	76	LBL	054	43	RCL
007	01	01	031	12	B	055	12	12
008	91	R/S	032	99	PRT	056	95	=
009	58	FIX	033	42	STO	057	35	1/X
010	00	00	034	12	12	058	65	×
011	99	PRT	035	98	ADV	059	43	RCL
012	42	STO	036	43	RCL	060	05	05
013	02	02	037	11	11	061	95	=
014	91	R/S	038	85	+	062	65	×
015	58	FIX	039	43	RCL	063	03	3
016	03	03	040	12	12	064	34	$\sqrt{X}$
017	99	PRT	041	95	=	065	95	=
018	42	STO	042	55	÷	066	42	STO
019	03	03	043	02	2	067	06	06
020	98	ADV	044	95	=	068	43	RCL
021	91	R/S	045	58	FIX	069	05	05
022	76	LBL	046	02	02	070	55	÷
023	11	A	047	99	PRT	071	43	RCL

(continued)

7.5 T.I. 59 SHUNT PROGRAM (CONTINUED)

072	01	01	112	95	=	152	07	7
073	95	=	113	85	+	153	05	5
074	42	STO	114	43	RCL	154	95	=
075	07	07	115	13	13	155	42	STO
076	45	Y^X	116	95	=	156	13	13
077	43	RCL	117	65	×	157	65	×
078	03	03	118	07	7	158	43	RCL
079	95	=	119	05	5	159	05	05
080	65	×	120	93	.	160	65	×
081	43	RCL	121	07	7	161	02	2
082	02	02	122	05	5	162	65	×
083	95	=	123	95	=	163	89	π
084	42	STO	124	42	STO	164	95	=
085	08	08	125	13	13	165	35	1/X
086	43	RCL	126	43	RCL	166	65	×
087	07	07	127	06	06	167	01	1
088	65	×	128	35	1/X	168	52	EE
089	09	9	129	75	-	169	06	6
090	00	0	130	53	(	170	22	INV
091	95	=	131	43	RCL	171	52	EE
092	42	STO	132	08	08	172	95	=
093	09	09	133	35	1/X	173	58	FIX
094	39	COS	134	54	)	174	02	02
095	35	1/X	135	95	=	175	99	PRT
096	33	X^2	136	65	×	176	22	INV
097	65	×	137	43	RCL	177	77	GE
098	43	RCL	138	13	13	178	13	C
099	07	07	139	95	=	179	43	RCL
100	65	×	140	42	STO	180	13	13
101	89	π	141	14	14	181	55	÷
102	55	÷	142	58	FIX	182	43	RCL
103	04	4	143	04	04	183	14	14
104	95	=	144	99	PRT	184	95	=
105	42	STO	145	43	RCL	185	58	FIX
106	13	13	146	09	09	186	01	01
107	43	RCL	147	30	TAN	187	99	PRT
108	09	09	148	65	×	188	98	ADV
109	30	TAN	149	07	7	189	91	R/S
110	55	÷	150	05	5	190	76	LBL
111	02	2	151	93	.	191	13	C

(continued)

7.5 T.I. 59 SHUNT PROGRAM (CONTINUED)

192	43	RCL	213	91	R/S	234	91	R/S
193	13	13	214	58	FIX	235	76	LBL
194	94	+/-	215	04	04	236	19	D'
195	55	÷	216	76	LBL	237	43	RCL
196	89	π	217	14	D	238	06	06
197	55	÷	218	43	RCL	239	58	FIX
198	02	2	219	01	01	240	01	01
199	55	÷	220	58	FIX	241	99	PRT
200	43	RCL	221	02	02	242	43	RCL
201	05	05	222	99	PRT	243	07	07
202	65	×	223	43	RCL	244	99	PRT
203	01	1	224	02	02	245	43	RCL
204	52	EE	225	58	FIX	246	09	09
205	03	3	226	00	00	247	58	FIX
206	22	INV	227	99	PRT	248	02	02
207	52	EE	228	43	RCL	249	99	PRT
208	95	=	229	03	03	250	98	ADV
209	58	FIX	230	58	FIX	251	58	FIX
210	03	03	231	03	03	252	04	04
211	99	PRT	232	99	PRT	253	91	R/S
212	98	ADV	233	98	ADV	254	00	0

ADDENDUM FOR THE MODEL 34A INSTRUCTION MANUAL

Because the relative accuracy of the rf millivoltmeter bears a direct relationship to the accuracy of loss measurements with the Model 34A Resonant Coaxial-Line, it is prudent to calibrate half-scale readings, relative to full scale, on the ranges of interest, i.e., 1, 3, and 10 mV. This addendum covers a simple calibration method.

Two equal metal-film resistors of approximately 25 ohms are connected as shown. The resistors should be matched on a precision dc bridge to ±0.25%, or better.

1. Connect the calibrating network to the output of the signal generator and set the output frequency to about 5 MHz.

2. Connect the probe of the rf millivoltmeter to point #1, and adjust the output level of the generator for a full-scale indication of the millivoltmeter (3 mV f.s. is the range used for most measurements).

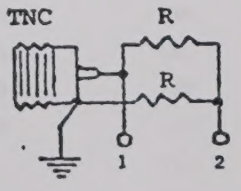
3. Connect the probe to point #2 and carefully record the indicated value. This is the indicated value for half scale that should be used for all measurements on the Model 34A.

It is important to realize that the absolute resistance values for the dividing network are not important, only that they be closely matched. Thus, it is the resolution and precision of the bridge measurement that is important, not the accuracy.

If it is not possible to match the resistors, two metal-film resistors of nearly equal value may be used for a first measurement. The resistors can be interchanged for a second measurement, and the arithmetic mean of the two indicated values of half scale can be used for 34A measurements.

It is also true that the relative, not the absolute accuracy of the rf millivoltmeter is important, except to know that the millivoltmeter is normal. A defect which results in an error of, say, 50%, or more, will demand greater coupling at the input of the line with the attendant possibility of increasing the line loss and measurement error. If the total series resistance of the dividing network is approximately 50 ohms, the setting of the output attenuator and the reading of the output meter should be sufficient to determine the condition of the millivoltmeter.

The relative accuracy of Boonton RF Millivoltmeters is sensibly independent of frequency on all ranges below 100 mV.



R ≈ 25 Ω, and
matched ±0.25%

A D D E N D U M

IN-WARRANTY TRANSPORTATION COSTS

When equipment is returned to the factory under our 1 year warranty, transportation costs are covered as follows:

1. First 3 Months

   To Boonton Electronics - Paid by Boonton
   To Customer - Paid by Boonton

2. Subsequent 9 Months

   To Boonton Electronics - Paid by Customer
   To Customer - Paid by Boonton

N O T E

SHIPPING & PACKING INSTRUCTIONS. To avoid the delays and expense of shipping damage call our Repair Department in advance for instructions on the best ways to pack & ship the equipment.

July 9, 1974
CD

MP MASTER
MA24746